Technical Document 2914
September 1996

Air-Mobile Ground Security and Surveillance System (AMGSSS) Project Summary Report

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Naval Command, Control and
Ocean Surveillance Center
RDT&E Division

San Diego, CA
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This work was sponsored by the Defense Special Weapons Agency under DSWA MIPR 96–2102 and Work Unit 82307 and by the Physical Security Equipment Management Office of the Army Aviation and Troop Command under MIPR 66041.

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ADMINISTRATIVE INFORMATION

The work detailed in this report was performed for the Defense Special Weapons Agency (DSWA), Alexandria, VA, and the Physical Security Equipment Management Office (PSEMO), Fort Belvoir, VA. Funding was provided under Program Element 0604322D, Accession Number DN301040.

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ACKNOWLEDGMENTS

This report resulted from the joint efforts of those on the AMGSSS project team. Most of team members work at the Naval Command, Control and Ocean Surveillance Center RDT&E Division (NRaD), San Diego, CA. D. W. Murphy and J. P. Bott, both at NRaD, contributed most of sections 1 through 4. Most of section 3.1 was abstracted from an article (reference 4) by Jim Cycon, Project Manager, UAV Technologies, for Sikorsky Aircraft Division, UTC, Stratford, CT.

The following NRaD personnel prepared most of the appendices as well as contributed portions to the body of the report: Dale Bryan, Jeff Coleman, Doug Gage, Bill Marsh, Brett Martin, and Hoa Nguyen.

Ron Schneider at Planalysis, San Diego, CA, a consultant to Computer Sciences Corporation, System Engineering Division, Springfield, VA, integrated and edited the document.

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1. INTRODUCTION

1.1 MISSION

The objective of the Air-Mobile Ground Security and Surveillance System (AMGSSS) project is to develop a system that can rapidly position remotely operated ground sensors at locations of operational interest and to provide information obtained by those sensors back to the operator. AMGSSS exploits the capabilities of small, remotely operated, vertical-take-off-and-landing (VTOL) ducted-fan aircraft to provide mobility to the sensor payload. These platforms can be operated effectively over the low-bandwidth tactical radio data links required by military users.

1.2 BACKGROUND

The AMGSSS concept grew from the Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division's (NRaD's) experience with the Ground Air Telerobotic System (GATERS) program (reference 1), initiated in 1986 by the U.S. Marine Corps. NRaD (then the Naval Ocean Systems Center [NOSC]) was the principal development agent on the system. GATERS consisted of a land-based, Tele-Operated Vehicle (TOV) and the Airborne Remotely Operated Device (AROD). The TOV was developed to perform remote reconnaissance/surveillance with direct fire and target designation/ranging capabilities. The TOV was based on a High-Mobility-Multi-Wheeled-Vehicle (HMMWV) platform (reference 2) for which AROD provided airborne reconnaissance and surveillance. Experience with the TOV demonstrated the value of remotely operated reconnaissance systems and also demonstrated that a full-time operator and high-bandwidth data link are required for effective mobility. The TOV used a fiber-optic communications link to provide the required bandwidth in non-line-of-sight situations. The military users did not want to be encumbered with the fiber-optic tethers and preferred that one operator be able to supervise several remote systems.

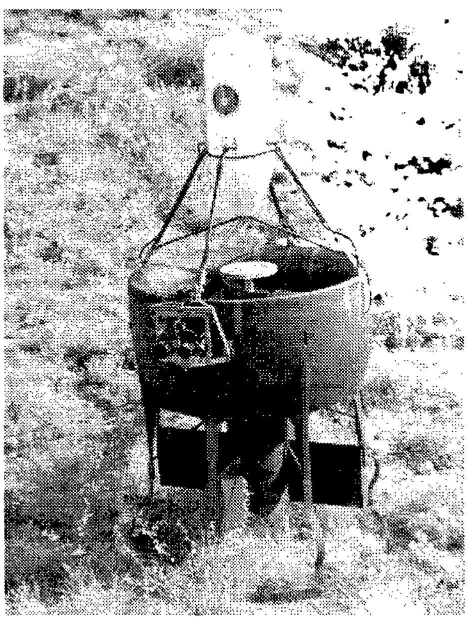

Figure 1. Airborne Remote Observation Device (AROD).

The AROD, figure 1, was a ducted-fan VTOL air vehicle that could easily translate through the air and provide aerial surveillance. The AROD was controlled from a portable ground-control station over a fiber-optic data link, with a radio control link as a backup. AROD had limited flight endurance and payload capabilities.

The AMGSSS concept combines the rapid mobility and low-data-rate control aspects of VTOL platforms with the long-endurance surveillance capabilities of the unmanned ground vehicles.

1.3 PROGRAM SPONSORSHIP AND MANAGEMENT

The AMGSSS program has been managed by the Physical Security Equipment Management Office (PSEMO), Ft. Belvoir, VA, and sponsored by the Office of the Undersecretary of Defense (Acquisition, Tactical Systems/Land Systems). NRaD is supporting PSEMO as the program

technical direction and development agent. The system was envisioned as supporting tactical security and force protection requirements. For fiscal year (FY) 1996 this work was sponsored by the Defense Nuclear Agency (DNA) (now called the Defense Special Weapons Agency [DSWA]) under DNA MIPR 96-2102 and Work Unit 82307 and by PSEMO under MIPR 66041.

2. OPERATIONAL CONCEPT

AMGSSS will support light and heavy early entry forces with a rapidly deployable, highly mobile sensor system that provides extended-range surveillance, detection, and identification for force protection and tactical security throughout the battlespace. AMGSSS will give combat, combat-support, and combat-service-support battalion/company/combat team commanders near-real-time situational awareness. It will expand the areas of the commander's influence, reduce hazards to the soldier, and provide early warning and assessment of enemy threats (reference 3).

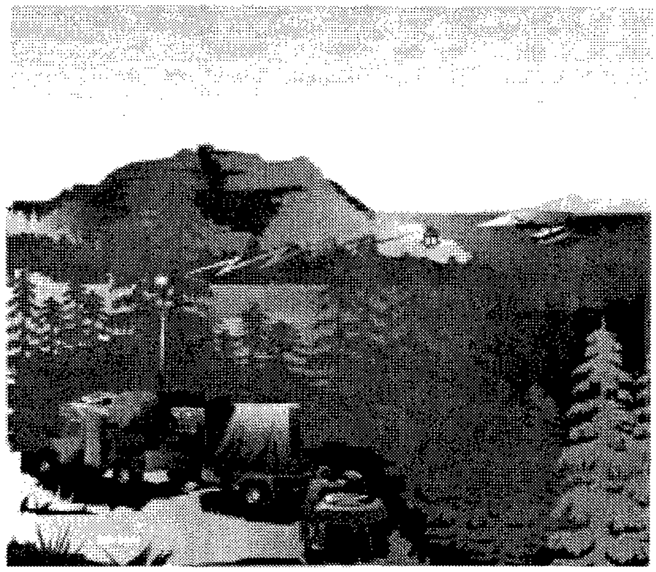

Figure 2. AMGSSS operation.

The system, figure 2, consists of three air-mobile, remote ground sensor units, a HMMWV-mounted base station, and a 3/4-ton trailer for ground transport of the Air-Mobile Platforms (AMPs). The trailer will be towed by the HMMWV. The AMPs are small (less than 300 lb and 6-ft diameter) units that transport the sensor payload to the operational sites. The units do not perform aerial observation, but simply move the sensors from one ground location to another where they perform extended observation. AMGSSS will allow the field commander to quickly extend his information-gathering perimeter out 10 km. The three platforms can be deployed as a barrier to detect intrusions or deployed independently to monitor assets, critical routes, or choke points. The sensors provide long-term surveillance without putting personnel at undue risk. The unit's rapid mobility and insensitivity to intervening terrain allow it to be quickly relocated to operationally relevant locations if the threat area moves.

The AMGSSS system will be operated by three military personnel. Upon arriving at the deployment site, two soldiers will off-load the AMPs from their trailer while the third soldier, using the mission planner and the operational orders, locates the observation sites for AMP deployment. Consideration in selecting sites must include field of view for the sensors, terrain compatibility for landing, and near-line-of-sight with the base station for communications. The coordinates of the selected sites and required transit waypoints and altitudes would then be down-loaded to the platforms.

After checkout at the launch site, each AMP will autonomously fly to its designated surveillance site. When the platform reaches the specified landing coordinates, it will transmit an image of the terrain at the site for the operator to make a landing decision. Once the site is determined to be suitable, the operator will give the command and the unit then lands itself. Depending on terrain type and quality of the information available to the operator, the platform may have to send several images as it descends. The high-level supervisory control capabilities and three-dimensional mobility allowed by the VTOL platform are ideally suited to this concept. If (during landing) there is loss of communications detected on the platform (due possibly to intervening terrain), the platform will simply elevate until communication is re-established with the base station, and then the platform will be directed to an alternate observation location.

The three AMPs will be deployed sequentially up to 10 km in less than 30 minutes each. Once landed, the platform will power down, and the sensor suite will go through a set-up sequence to provide sensor coverage of the region of interest. The sensor payload will consist of a daylight imaging camera, a forward-looking infrared (FLIR) camera, an acoustic sensor unit for self protection and imager cueing, and a laser rangefinder. Sensor processing will be performed on the platform to detect significant motion and/or acoustic signatures before alerting the operator. The portion of the image containing the potential target will be sent to the operator and displayed within the corresponding image stored in the operator's work station. The operator may then choose to get a range reading. Each AMP can be repositioned at least one time during its mission. Upon completion of the mission the operator will command the remote platform to restart, take off, rise vertically to its transit altitude, and return to the base station.

Communication between the AMPs and the base station will be over a tactical-radio-based data link. The control and communication architecture will support use of modular mission packages such as communications relay, barrier/minefield detection, and nuclear/biological/chemical agent detection.

3. SYSTEM DESCRIPTION

The AMGSSS is composed of two physically independent portions: the air-mobile portion and the ground-mobile portion. The air-mobile portion consists of the air-mobile platform and the mission payload that it carries. The ground-mobile portion consists of an HMMWV on which a control display center is mounted, and a trailer that carries the air-mobile portion before deployment for surveillance. This section describes the prototype system design features.

3.1 AIR-MOBILE PLATFORM

The air-mobile platform (references 4, 5, and 6) is the mobility system that transports the sensors and communications payload from one operational site to the next. The current system design is based on the Sikorsky Cypher vehicle (a ducted-fan, VTOL, unmanned aircraft) with a sensor pod mounted on top (figure 3). Projected weight of the mission-ready AMP is 270 lb, including the 60-lb mission payload and fuel. Sufficient energy will be available to operate the sensors in surveillance mode for 12 hours and to restart the engine twice. Weight and power estimates are based on commercially available hardware, modified in some cases for the AMGSSS application. The AMP will carry sufficient fuel for a 30-km transit and three takeoffs and landings.

Figure 3. Air-Mobile Platform (AMP).

3.1.1 Background

The following sections describe details of the Sikorsky Cypher vehicle, which is the current AMP baseline.

The Cypher, shown in figure 4, is based on a combination of proven coaxial rotor technology demonstrated with the Sikorsky Advancing Blade Concept (ABC) aircraft of the 1970s and shrouded fantail technology demonstrated with the S-67 aircraft and S-76 LH Fantail Demonstrator aircraft. The Cypher is configured with two counter-rotating four-bladed rotors shrouded by the airframe. The airframe or shroud houses propulsion, avionics, fuel, payload, and other flight-related hardware. The Cypher concept is an innovative approach because it is the first and only ducted configuration that uses collective and cyclic pitch on the rotor blades to control lift and moments about the three body axes. The result of this approach is a very maneuverable platform with excellent hover efficiency.

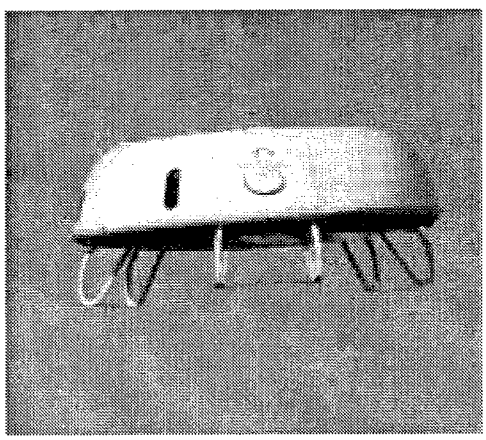

Figure 4. Cypher.

3.1.2 Duct Aerodynamics

The performance characteristics of the Cypher are a function of both the rotor and the shroud trim states. Performance predictions required the superposition of classical duct aerodynamics with the nonuniform flow, which occurs from the cyclic blade pitch used for aircraft trim. As a ducted device transitions from a hover state into forward flight, the shroud will see two components of flow. The simplest is flow over the shroud as it would occur without the presence of a rotor. This flow has been tailored, through external shroud shaping, to produce a negative (nose down) moment to partially offset the second flow component. The second flow component is the induced flow through the duct, which will be nonuniform due to both the forward flight velocity and the cyclic blade pitch. The nose-up pitching moment due to induced flow is zero in hover, increases to a maximum at about 40 knots, and then diminishes. The rotor cyclic trim requirements thus result in an increase in power from the hover condition to about 40 knots, with a reduction in power thereafter.

3.1.3 Physical Characteristics

The physical characteristics of the Cypher Technology Demonstrator (TD) aircraft are presented in table 1, and a brief description of major subsystems follows.

Table 1. Cypher physical characteristics.

Overall Dimensions		**Rotor**	
Fuselage length (ft)	6.5	Number of rotors	2
Fuselage width (ft)	6.5	Rotor separation (in)	11.0
Fuselage height (ft)	2.0	Rotor radius (ft)	2.0
Fuselage cross sectional (in)	19.5 h x 15 w	Tip speed (ft/s)	650
		Blades per rotor	4
Volumes			
Structural volume (ft^3)	23.4	**Drive System**	
Fuel tank volume (ft^3)	0.92	Engine RPM	6500
Sensor payload volume (ft^3)	1.6	Gearbox	Spiral Bevel
		Gear reduction	2.31:1
		Fuel type	Auto Gas
Weights			
Weight empty (lb.)	170		
Normal takeoff weight (lb)	255		
Max. gross weight (lb)	300		
Usable fuel weight (lb)	40		
Sensor payload wt. (max. lb)	45		

3.1.4 Rotor

The rotor is an all-composite, bearingless system designed for enhanced reliability and maintainability at a reduced weight. In the bearingless rotor, pitch motions of the blade are accomplished by twisting rectangular-shaped beams. The beams are stiff in bending but torsionally soft. A torsionally stiff torque tube surrounds the flexbeams and transfers control motions from the control actuators to the outboard end of the flexbeam. Six actuators, three connected to each rotor swashplate, are incorporated for independent control of each rotor. By using a coaxial, counter-rotating rotor system, no anti-torque device is required, and differential collective can be used for directional control.

3.1.5 Airframe

The Cypher airframe is an all-graphite composite reinforced structure that consists of an inner shroud, outer shroud faring, bulkheads, support struts, and center mounting structure. The inner shroud wall is the major support surface for mounting the engine. The support struts are the primary structure and provide a load path between the rotor system and the external shroud. Externally, the airframe is shaped to be aerodynamically efficient in both hover and forward flight.

3.1.6 Engine

The aircraft is powered by a Norton Motors (now known as UAV Engines) rotary engine, Model NR801T. The Norton engine has a high power-to-weight ratio and a good partial-power fuel consumption. The NR801T is a combination air- and liquid-cooled engine that produces 45 hp at 6,000 rpm. The NR801T used incorporates a magneto-powered, twin-spark-plug ignition system. Engine operation is controlled and monitored by the aircraft flight-control system.

3.1.7 Transmission

The transmission drive system consists of a gearbox and drive shaft connected to the rotary engine. The gearbox has a spiral bevel gear set located between the two rotors. Torque is transmitted through the drive shaft, to the pinion, through the bevel gears, and into the vertical torque shafts, thereby turning the rotor hubs and blades.

3.1.8 Avionics

The avionics architecture is based on the philosophy of a central processor. The Vehicle Mission Processor (VMP), the brain of the system, integrates airborne sensors and controls aircraft flight, navigation, vehicle management, payload, and communications. For the demonstration aircraft, the Honeywell Integrated Flight Management Unit (IFMU) was selected for the VMP. The IFMU comprises a GG 1308 IFMU, a 1750A processor module, a power supply module, and a flexible I/O module. The IFMU uses state-of-the-art ring-laser gyros and highly accurate accelerometers for inertial measurements.

The VMP receives rates and accelerations from the IMU, and through strap-down navigational software, provides the flight-control software with 3-axis linear accelerations, angular rates, linear velocities, vehicle attitudes, and vehicle position. The strap-down equations are updated by a Global Positioning System (GPS) via a Kalman Filter resident in the VMP. A Radar Altimeter is incorporated to provide accurate altitude and assist in the vertical control of the air vehicle during automatic launch and recovery.

All software in the VMP is written in Ada. There are three top-level modules hosting mission management, flight controls, and strap-down navigational software. The mission management and flight-control software was developed, coded, and integrated by Sikorsky. The navigational software was an integral part of the Honeywell IFMU. Software integration and validation was conducted on an integrated hot bench consisting of a real-time simulation model and actual flight hardware.

3.1.9 Flight Controls

One of the major objectives of the Cypher TD program is to demonstrate a user-friendly VTOL aircraft that can be easily controlled with simple operator commands. For this reason, the flight-control software is configured to receive simple inputs, such as vehicle heading, altitude, and cruise

velocity. The aircraft automatically calculates the required rotor inputs to achieve the desired flight conditions. With simplified operational commands, the operator can spend more time with payload operations rather than with piloting the aircraft. Automatic modes such as heading hold, altitude hold, velocity hold, position hover hold, auto takeoff, and auto land have been incorporated to simplify vehicle positioning during a mission or operation from confined areas.

3.2 MISSION PAYLOAD

The mission payload consists of the sensor suite, onboard controller, communications, and battery power pack. The AMP serves as the transport platform for the mission package. All communication between the platform and the control station passes through the mission payload.

3.2.1 Sensor Suite

The sensor suite comprises two subsystems: the landing sensors and the mission sensors. The landing sensors provide information to the operator on the suitability of the selected landing site in terms of slope, vegetation, and roughness. The present approach is to use imagery from downward-pointing cameras that is transmitted to the operator for landing site assessment. Photogrammetric and laser-scanning techniques are potential methods for slope and roughness assessment.

The mission sensor payload includes a daylight video camera, a forward-looking infrared (FLIR) camera, a laser range finder, and an acoustic sensor for queuing to target presence and location. The video and thermal imagers are mounted on a pan-and-tilt unit for scanning the optical sensors over the area of interest.

3.2.2 Onboard Controller

The onboard controller coordinates communications, image processing, sensor control, and commands to the vehicle flight-management unit. Image processing is handled by an image-processing unit within the controller. Several technologies are under evaluation for image processing and data compression.

3.2.3 Communications

The communications subsystem transmits commands from the Control Display Center (CDC) to the AMP in the air and on the ground at its remote site. The subsystem also transmits compressed surveillance data (including FLIR or TV images) and status from the AMP to the CDC. Tactical radios interoperable with Single Channel Ground and Airborne Radio System (SINCGARS) as well as high-speed, line-of-sight, radio frequency modems have been used for communications..

3.2.4 Batteries

Silver-zinc battery technology has been selected for the prototype system since it provides high-energy density, is readily available, and has known characteristics. This is not the technology that would be used in an operational system. The secondary battery industry, which is being driven by the electric transportation and portable consumer electronics industries, is making a substantial investment in battery technology. We closely monitor the state of the art and will use the best available technology when the system design is finalized. Promising technologies include nickel metal hydride, lithium-ion, and zinc-air.

3.2.5 Payload Weight and Power Estimates

Tables 2 and 3 provide weight and power estimates for the payload subsystems. In addition, the total energy requirements have been estimated in order to size a battery. A number of assumptions were made in this analysis.

The ground mission was selected as 12 hours. This allows use of currently available silver-zinc batteries with a reasonable battery weight. Future advances in battery energy density would provide extended ground surveillance times.

The duty cycle for the video camera was assumed to be 50 percent and for the FLIR 100 percent. The FLIR will be useful at night and in the daytime for classification. To provide these capabilities, the FLIR cooler must be kept on at all times (about 4 watts) since cool-down time is 10 minutes.

The acoustic sensors and onboard processor were given a 100-percent duty cycle.

The communications transmitter was assumed to be on 10 percent of the time. This would imply a smart image compression system that only sends back the minimum information for target update data due to the low bandwidth available.

Table 2. AMGSSS concept payload weight and power estimate.

Subsystem	Weight (lb)	Power (W)	Source
Video 1	1	3	Cohu
Zoom lens (incl. motors)	2	1	Canon
FLIR	3	5	Inframetrics
FLIR zoom lens	5 *	0	DIOP
Acoustics	2	2	Lockheed Sanders
Pan & tilt	4	1	TRC
Laser rangefinder	4	5	Melios
Landing video camera	0.5	1	Cohu
Landing near IR illuminator	2	100	NVEC
Communications (VHF)	5		Racal PRC – 139
(SINCGARS interoperable)			
(incl. antenna)			
Idle		0.8	
Send		50	
Receive		10	
Onboard processor	15	20	
Battery/power conditioning	17		Yardney Ag Zn (60 W-hr/lb)
Avg. Total**	**60.5 lb**	**64.5 W**	

* Zoom is a lens "switchout"; requirement for this needs systems analysis.

** "Typical" duty cycle on various subsystems gives 774 watt-hour requirement over 12-hour mission time on ground.

Table 3. System battery estimate.

Subsystem	Power (W)	Duty Cycle(*) % of 12-hr mission	Energy (12 hr) W-hr
Video	3	50	27 **
Zoom lens (incl. mtrs)	1	10	2 **
FLIR	5	100	90 **
FLIR zoom lens	5	1	1 **
Acoustics	2	100	36 **
Pan & tilt	6.25	100 Controller 23 Motors	112 **
Communications (VHF)			
Idle	0.8	80	8
Send (Hi Power)	50	10	60
Receive	2.8	10	3
Onboard processor	20	100	360 **
Engine start (3 starts)	2000	30 sec ea.	75 **
Total			**774 W-hr**

* Duty cycle is percent "on time" during typical 12-hr mission.

** These items will probably require "DC–DC power conversion," assumed to be 66.7-percent efficient.

The engine electrical starter requirements assumed three starts of 30-second duration. This would accomplish the initial deployment to a remote site, deployment to an alternate location, and return home. The initial start may be by an electrical umbilical.

Finally, the visual, acoustic, and onboard processor were assumed to require power conditioning electronics. Conservatively, a 33-percent power loss was assumed in the power conversion. The communications equipment was assumed to run off the battery directly.

3.3 CONTROL DISPLAY CENTER (CDC)

The operator interface is based on workstation and graphical user interface technology and will be housed in a HMMWV equipment shelter. One operator will control and monitor the three AMPs. An alert will be given when images or sensor information requiring evaluation come in from the platform. The operator will have the option at any time of taking control of the sensors on any AMP and obtaining images of the surroundings. The CDC will also house a GPS unit to determine its position and communications equipment for connectivity to higher echelons.

The CDC will include an automated mission planner to support the operator in selecting the landing sites for the AMPs. Considerations in selecting observation sites include sensor coverage of the mission area, terrain suitability for landing, and communications to the CDC. The mission planner will be based on digital-terrain-database technology and supporting algorithms to aid in site selection.

4. SYSTEM STATUS

Investigation of the AMGSSS concept was begun in FY 92. Technical summary reports were prepared at the end of FY 92 and FY 93 (references 7 and 8). Appendix A describes how the program evolved from its inception. The following paragraphs summarize the accomplishments under each major subsystem area.

4.1 AIR-MOBILE PLATFORM

The Air-Mobile Platform is the key component of the system. Cypher (figure 4) a ducted-fan, VTOL, autonomous flight, remotely controlled takeoff and landing vehicle was selected as the flight platform for the AMGSSS. Cypher was developed by Sikorsky primarily with corporate funding. Development and testing of the Cypher over the past 2 years has demonstrated the following capabilities:

- Fully autonomous takeoff and landing.
- Landing on slopes to 13 degrees with indications that greater slopes were possible.
- Supervised autonomous flight control and navigation, including hover hold, position hold, altitude hold, velocity hold, and "return home."

Under contract to NRaD, Sikorsky conducted a design concept study (reference 5). Appendix B is abstracted from reference 5 and provides vehicle design concepts for the AMGSSS mission as envisioned at that time. Subsequently, some concepts have been modified.

4.2 MISSION PAYLOAD PROTOTYPE INCLUDING CONTROL STATION

In FY 95, program funding prevented NRaD from proceeding with the updated plan for full system development (reference 9). Instead, NRaD undertook the development of an AMGSSS Mission Payload Prototype (MPP). The MPP consists of two units analogous to the two components of the AMGSSS, i.e., the AMP payload (remote unit) and the CDC. The MPP remote unit, shown in figure 5, comprises the video camera, FLIR, laser range finder, subsystem controller/payload processor (PP), pan-and-tilt unit, and the payload portion of the communications subsystems proposed for the AMGSSS prototype. The Control Display Center (figure 6) contains the base station portion of the communications subsystem and a laptop computer operator interface. Figure 7 is a block diagram of the MPP.

The objective of the MPP is to explore the integration issues of the payload, communications, and operator interface. The MPP also provides a platform on which to test various data compression, image processing, and target-detection hardware and software. The MPP allows early interaction with the user community on how users would use the information available from the remote platforms and evaluation of operator interface and communications issues. The MPP has been breadboarded and run through preliminary debugging and demonstration trials. Both the Racal PRC-139 and SINCGARS tactical-band radios are being used for communications, as well as radio frequency Ethernet modems.

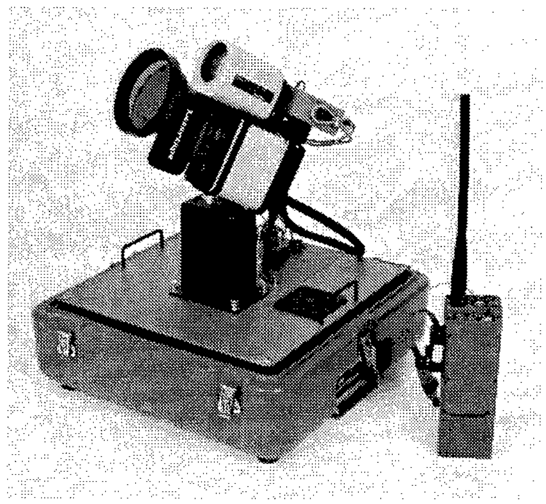

Figure 5. MPP remote unit.

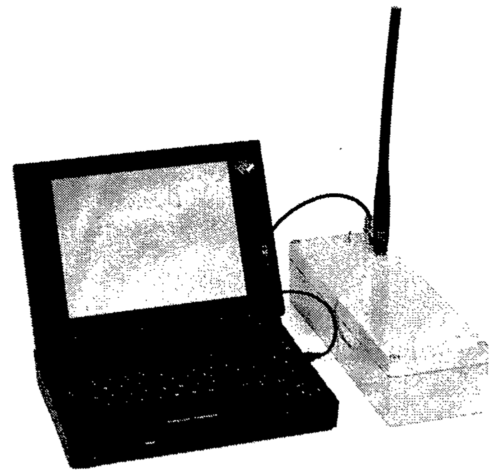

Figure 6. MPP control display center.

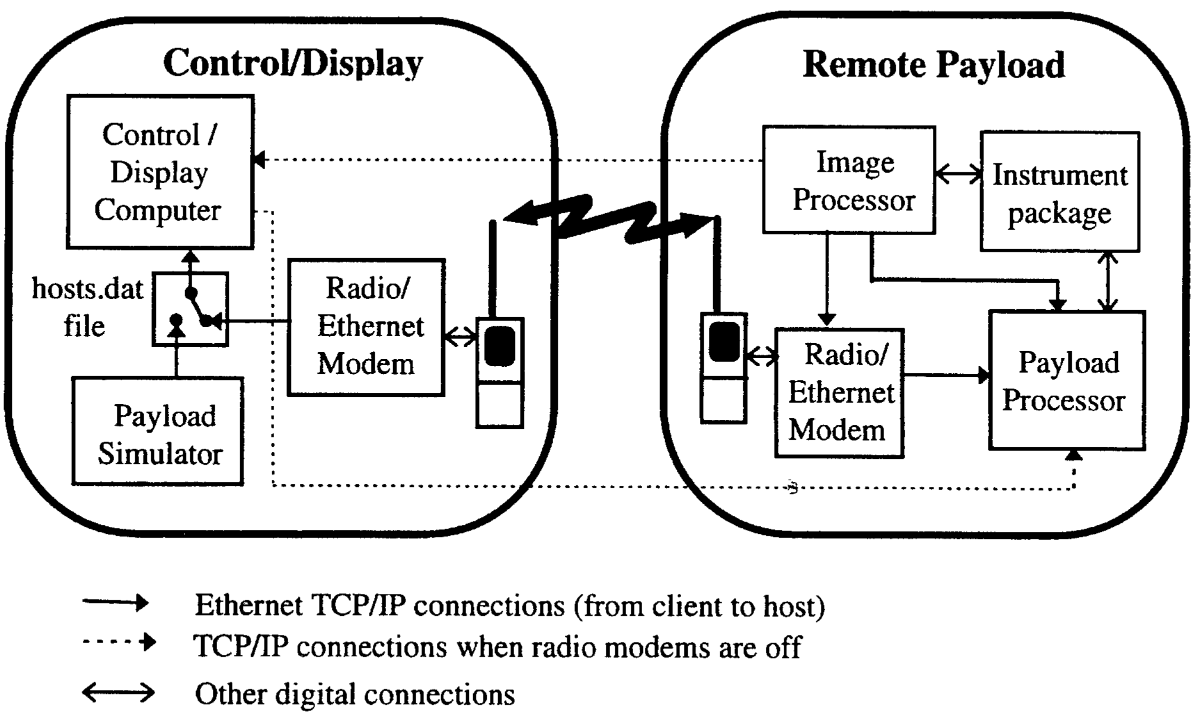

Figure 7. AMGSSS MPP system.

4.2.1 Communications

A PC-card version of the Tactical Communications Interface Module (TCIM) is used to interface the computers with the radios. The data throughput with error correction and standard military protocols is on the order of 4000 to 8000 bits per second.

As an initial evaluation of the non-line-of-sight communications performance, the remote portion of the MPP breadboard was mounted in a HMMWV. Images were collected and transmitted from

the HMMWV as it was driven around the NRaD facility on Point Loma, San Diego. SINCGARS radios were used as the small PRC units had not yet been received. Images from the moving vehicle on one side of Point Loma were received reliably at NRaD's Bayside facility on the opposite side. 256-by-256 pixel images were transmitted at a rate of 3 frames per minute with the 4-kilobit data rate.

Appendix C presents additional information on radio selection.

4.2.2 Sensors

Sensors for the MPP are those that are proposed for the AMGSSS prototype. The selection was based mainly on performance, weight, and power consumption. The FLIR is the Inframetrics Infracam. After 3 days and 1 night of testing at Camp Pendleton, CA, the Infracam with a 100-mm lens showed its sensitivity to be adequate to discern moving targets at up to 5 km. A Cohu 2122 black and white video camera with Canon J10X10 (10 to 100 mm) zoom lens with a 2X range extender was selected for daytime imagery. We intend to use the Contraves laser range finder that is based on erbium-glass technology and weighs 0.6 kg, but selected the Riegl Lasertape as a short range (1 km), low-cost, interim solution for the prototype.

It was difficult to find an off-the-shelf pan/tilt that could meet weight, payload, speed, and position-feedback requirements. The closest to meeting such requirements was the TRC Zebra unit, which has a limited weight capacity. The motor design was analyzed, found adequate, and then tested with a pair of 5-lb weights mounted to simulate the anticipated rotational inertia. Performance was adequate if speeds were kept to less than 100 degrees per second.

Three acoustic detection systems have been qualitatively evaluated in the field. The systems showed promise, but none met all of our criteria.

Appendix D provides additional information on the selection of sensors for the MPP.

4.2.3 Image Processor

The MPP image processor (IP) performs the image processing, including source (FLIR/TV) selection, frame grabbing, image contrast enhancement, video motion detection, and image/video compression. The IP will serve as a testbed for applications related to remote day/night video surveillance using small low-power, embedded-image-processing hardware.

Three variations of the IP hardware were evaluated: (1) an X86 central processor unit (CPU) and frame grabber, (2) an X86 CPU and digital signal processor (DSP) frame grabber, and (3) an X86 CPU and application-specific integrated circuit (ASIC) vision processor. The image-processing algorithms are hosted differently among these three configurations. Configurations (1) and (2) are PC/104-based, while (3) is ISA-based. Configuration (3) provides the highest performance capability. As an embeddable image-processing testbed, the IP will be used to investigate and develop robust algorithms for remote video surveillance applications. These algorithms include error resilient image/video compression for transmission over noisy radio channels; camera image stabilization for image jitter induced by wind; better compression techniques for low-bandwidth channels and directed motion detection for low signal-to-noise video sequences.

Appendix E provides additional information on image processing for the MPP and AMGSSS.

4.2.4 Onboard Controller

The AMGSSS MPP Remote Platform's onboard controller, with the Payload Processor (PP) as its core, implements a well-defined "server" functionality, executing commands it receives from the CDC, and (especially for debugging purposes) from other clients, including the PP's own Command Line Interface (CLI). Mechanisms implemented on the PP support debugging as well as operational requirements, and have been designed to easily accommodate the integration of additional or enhanced sensor subsystem components. The PP communicates via RS-232 links with microcontrollers embedded within several commercial off-the-shelf (COTS) subsystems: pan/tilt unit, FLIR, laser rangefinder, and acoustic detection system. These microcontrollers maintain internal state information that should be "mirrored" by the subsystem state information held by the PP itself.

Appendix F describes the onboard controller for the MPP in greater detail.

4.2.5 Control Display Center

A portable operator Control Display Center, shown in figure 6, has been developed for the MPP using software running under the Windows operating system. The use of network communications allows the program to control the remote sensor package and display the remote sensor status as well as images transmitted in real time. Special attention was given to creating an operator interface that is simple and intuitive to use. The operator is able to point and click with a mouse to do most operations necessary to control the remote unit.

Appendix G describes the Control Display Center for the MPP in detail.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 OVERALL

As concluded in the U.S. Army Missile Command (MICOM) report (reference 10), PSEMO and NRaD have made good use of minimal funding for conceptual studies, research, and development on the AMGSSS. Since the MICOM report (reference 10) was prepared, additional flight tests of the platform and field tests of a prototype payload and portable control display center have demonstrated the technical feasibility of the AMGSSS concept.

At the overall system level, one of the next important steps would be the integration of the payload with the flight platform. Conclusions and recommendations regarding the various subsystems that compose the AMGSSS are presented in the following sections.

Inadequate funding prevented the program from reaching its goal of developing and testing a complete operating demonstration model of the system in 4 years. It is recommended that the program be continued as an Advanced Technology Demonstration or Advanced Concept Technology Development project.

5.2 AIR-MOBILE PLATFORM

Further development and testing of the air-mobile platform is required to:

- combine an increase engine power with a reduction in weight in order to increase the flight speed and environmental/operational envelope
- reduce the engine-noise signature further
- reduce platform complexity and cost
- provide for supervised landing at remote unprepared sites (including landing site evaluation)
- demonstrate stable flight in AMGSSS configuration, i.e., with simulated sensor pod mounted
- incorporate remote engine start
- provide for heavy-fuel utilization

5.3 SENSOR SUITE

5.3.1 Visual Imaging

The Cohu 2122-1024 camera with the Canon J10X10REA-IAII zoom lens and a 2X range extender met all AMGSSS requirements for daylight video.

5.3.2 Thermal Imaging

The Inframetrics InfraCam was selected, with a 100-mm lens. This imager uses a platinum silicide focal-plane array for high uniformity and a proprietary Stirling cycle dewar cooler to combine light weight with low power and reasonably high image quality. The lens is a compromise to combine availability, long range, light weight, and low cost while not narrowing the view too much for panorama gathering. A dual-field-of-view lens would be preferable but would add significantly to the cost and 5 lb or more to the weight.

5.3.3 Laser Ranging

A Contraves laser rangefinder is recommended if the high cost is not prohibitive (or the price has dropped) and units are available. Alternatives include the Reigl Lasertape, if shorter ranges are sufficient, or the Melios if long range is required. Since the market is rapidly evolving, vendors should be contacted again at the time of procurement and new developments evaluated.

5.3.4 Azimuth-Elevation Mount

The Transitions Research Corporation's (TRC) Zebra model with NRaD modifications meets the needs of AMGSSS and is recommended.

5.3.5 Acoustic Sensor

Final selection of an acoustic sensor will depend on the AMGSSS vehicle. Until then, flexibility can be maintained through incorporation of an extra RS232 serial interface for communication with any acoustic sensor system. Several candidates are available, but none has been selected at this time.

5.3.6 Market Surveys

New market surveys will be performed if the program moves ahead to take advantage of improved technology and higher performance sensors.

5.4 IMAGE CAPTURE AND PROCESSING

The AMGSSS image-processing tasks have to be combined into an integrated image processing subsystem. This is the only approach that will satisfy the very restrictive requirements for power, weight, and cost without sacrificing subsystem performance. An integrated image-processing subsystem is one that incorporates compression, video motion detection, terrain slope determination, and various image-enhancement features. Any image-processing hardware solution should take advantage of recent developments in low power, programmable multiprocessor vision ASICs.

Image-preprocessing tasks should not be underestimated for tactical surveillance applications like AMGSSS. These tasks, including image stabilization, contrast enhancement, noise filtering, edge enhancement, and sensor fusion, play a vital role in providing the essential surveillance imagery data to the operator over low-bandwidth LPI/LPD tactical radio links.

We recommend funding two parallel approaches for developing an integrated image processor for AMGSSS: a downsized version of David Sarnoff Research Center's VFE-100 and the Delta Information System's Vidicoder vision processor board.

5.5 ONBOARD CONTROLLER

Recommendations for future development of the onboard controller follow.

5.5.1 Enhanced Robustness for Subsystem Control

Error conditions or other events of interest internal to the subsystems may not be adequately reported to or detected by the Payload Processor (PP). The PP should be enhanced to deal with these situations more robustly. Specifically:

- The low-level C code controlling the pan/tilt unit should be reviewed and revised.
- Additional error checks should be inserted into the low-level code interfacing the FLIR with the laser rangefinder.
- Opportunities for inserting LONWorks technology into the onboard controller should be reassessed.

5.5.2 Enhancement of Message Addressing

The message-addressing scheme used in AMGSSS should be refined to incorporate process ID within the platform or CDC as well as platform ID. The refinement should support flexible operation and debugging activities in an environment including both multiple AMGSSS vehicles and multiple CDCs.

It should be kept in mind, however, that the most critical current deficiencies in the AMGSSS MPP systems involve the tactical radio link and its controller, not the onboard controller. Moreover, once the radio link's performance has been optimized, it is almost certain that the details of the CDC's operator interface will become the focus.

5.6 COMMUNICATIONS

The fundamental question concerning the design of the AMGSSS communications subsystem is, "What frequency band should be used?" The selection was narrowed to two choices: the VHF tactical band or the commercial UHF band and their associated equipment. The advantages and disadvantages of each approach are discussed in detail in Appendix C.

Although the tactical band radios have the potential for beyond-line-of-site transmission, in real scenarios, performance is erratic and difficult to predict. Although standard tactical equipment may be used, special software is required, the radios must be shielded from radiation from the computers, and the data rate is low.

The commercial UHF band and equipment provide high data rates, data security, readily available small and lightweight hardware, and program control of hardware and software. However, repeaters would be essential, little standard military equipment could be used, and frequency allocation conflicts are possible.

In 1994, the tactical radio approach seemed to have the most merit: The capability of maintaining a radio link without maintaining line of sight was considered to be of paramount importance; the standardization of SINCGARS was very attractive; and the usage of existing military communication protocols was very practical. In practice, a predictable radio link was found to be more valuable than a versatile one; the lightweight SINCGARS substitute was not a strong performer; and the existing protocols were found to be inappropriate for our application.

The tactical radio system could be improved by adding another radio to create full-duplex communications, using the new dual-channel PC Card TCIM from Magnavox, fixing the shielding problem with the Racal radios, changing our communications' architecture to one that can reliably handle data errors, and completely changing the radio control software. If these changes were made, the data rate would increase to 6000 to 8000 bits per second, no link initialization would be needed, and the latency would decrease by an order of magnitude. However, the actual effects of real hills would still be somewhat unpredictable, and the data rate would still be a fraction of our true requirements.

Therefore, a change to a wireless (UHF) LAN should be seriously considered. This approach would require a repeater in most circumstances. Use of a repeater does create some practical disadvantages. However, the virtues of a predictable link, straightforward software, and a high data rate seem to be more important factors when the system is actually used. For in-flight operation, a VHF backup receiver should be used, but this would not add significantly to the overall weight of the payload.

A market survey is recommended to determine the best candidates for wireless LAN transceivers. Then, those candidates should be tested to reveal unforeseen problems. If the wireless LAN performs well in the field, we suggest that these units replace the current tactical radio system. However, it may be desirable to retain the current tactical radio system hardware for in-flight backup communications.

5.7 BATTERIES

Further evaluation of battery technologies needs to be conducted to verify or revise estimates of their ability to provide the power needed by the AMGSSS for powering the system and restarting the platform engine at remote sites.

5.8 CONTROL DISPLAY CENTER

The Control Display Center has been developed to meet the immediate needs of the AMGSSS Mission Payload Prototype. In order to expand the system to the original AMGSSS system objectives (references 11, 12, 13, and 14), various changes will be needed including:

Conversion to a 32-bit operating system such as Windows-NT. The power of a 32-bit operating system will be needed to address the following five issues:

1. Incorporating three-dimensional maps, such as DMA-supplied DTED (elevation data) and ADRG (raster) maps. A combination of maps such as the two mentioned will be necessary to generate a 3-D map of the environment to enhance operator awareness and allow mission planning on the Control Display Center.
2. Adding mission planning capabilities. This includes programming and supervision of the flight and landing of the air-mobile platforms.
3. Expanding support to three air-mobile platforms/sensor suites.
4. Addition of the video-streaming capability.
5. Enhancing the user interface based on feedback from operators during field tests.

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*For further information, contact the Adaptive Systems Branch, NCCOSC RDT&E Division, San Diego, CA 92152–5001.

APPENDIX A: PROGRAM EVOLUTION

The technical development plan for the AMGSSS (reference A-1) called for three development phases plus two test phases leading to the Milestone II decision. Figure A-1 shows timelines for the work actually conducted through FY 95. Figure A-2 illustrates the plan, as of the end of FY 94, for taking the system to Milestone II.

In Phase I, technologies applicable to the system were surveyed, and a system concept was formulated. The early portions of Phase II involved further subsystem technology evaluations including tests and demonstrations of the flight platform. In Phase II, the platform contractor was to further develop an existing platform and apply lessons learned to the design and fabrication of a new air-mobile platform. In parallel, NRaD was to acquire/develop the prototype payload subsystems and a Control Display Center for operation of the system. The payload equipment would be given to the platform contractor for integration with the flight platform. The platform would then be integrated with the control display system, and the entire prototype system would be extensively tested.

Phase III would follow the same general course as Phase II, but three flight platforms with their payloads would be assembled and integrated with a new Control Display Center. After Phase III testing, the system would go into Technical Feasibility Testing and then Early User Evaluations.

CONCEPT FEASIBILITY: JULY–OCT 1992, PHASE I

In the last quarter of FY 92, NRaD performed an AMGSSS concept feasibility study by assessing the availability and maturity of the required subsystem technologies and developing preliminary power and weight budgets for the air-mobile platform (AMP) (reference A-2, p. 21). This work indicated that the concept was feasible; that is, there were technologies available that had demonstrated the general function and level of performance required. The investigation also supported the preparation of a program plan that included the schedule and cost for a system demonstration.

MARKET SURVEY: FY 1993, PHASE I (CONTINUED)

In FY 93, the Physical Security Equipment Management Office (PSEMO), Ft. Belvoir, VA., tasked NRaD to perform a market survey (availability of products for use in AMGSSS), develop draft evaluation criteria, and perform Trade-Off Determination and Best Technical Approach analyses, where possible, to support preparation of the Concept Formulation Package by the Program Office. The AMGSSS was divided into subsystems. For each subsystem, functional requirements were determined. Then technology surveys were conducted. Literature was searched and contacts made with companies, academic institutions, and individuals with expertise in the relevant technical areas. For each subsystem, alternatives were formulated for performing the functional requirements, trade-off analyses conducted, options evaluated, and the best technical approach selected. In several subsystem areas, final decisions had to await field evaluations in AMGSSS-specific situations or finalization of the operational requirement. A detailed report of the investigations was published (reference 2).

The market surveys had not indicated an abundance of demonstrated, mature air vehicles suited for the role of the AMGSSS air-mobile platform. Therefore, it was decided to canvass industry to determine if this capability could be demonstrated, and in April 1993, a Broad Agency Announcement (BAA) was published soliciting proposals for AMGSSS platforms. The announcement outlined a three-phase program. In Phase I, vertical takeoff and landing and transition to horizontal flight

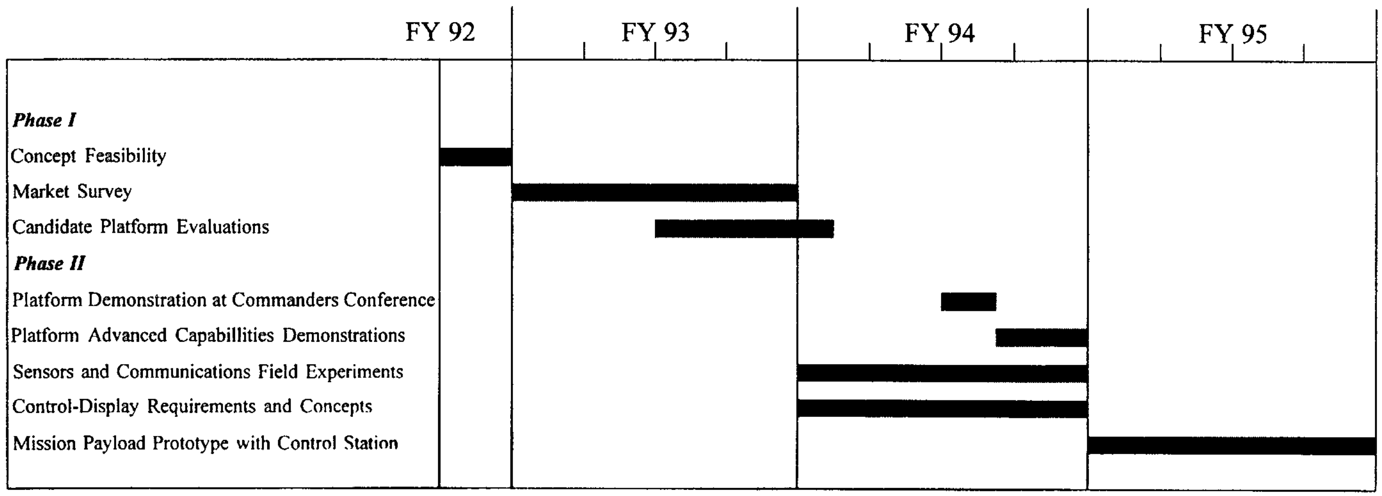

Figure A-1. AMGSSS development work performed.

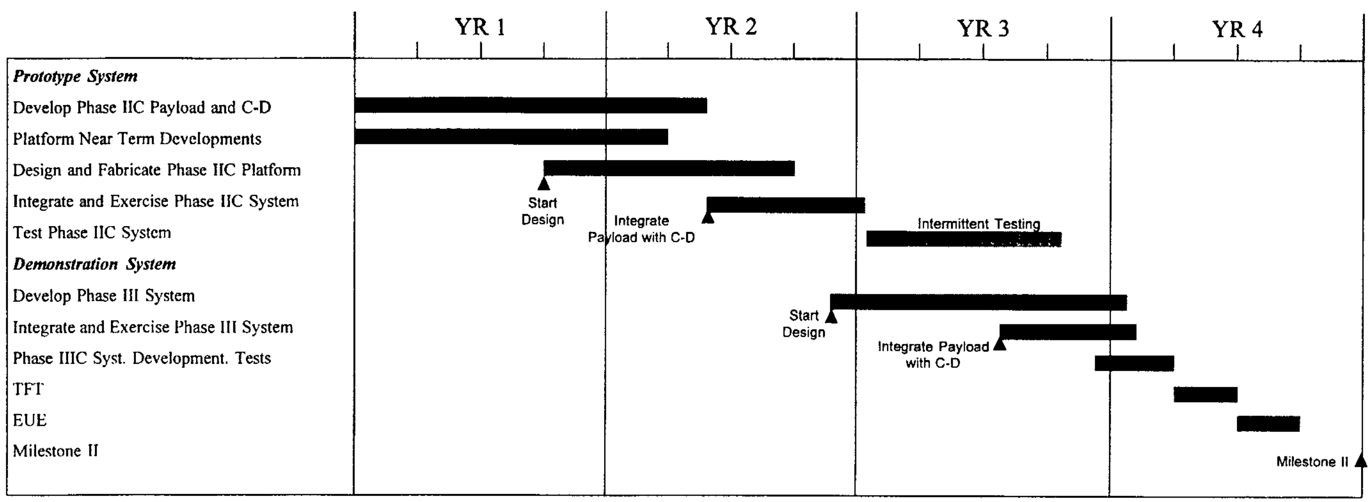

Figure A-2. Final revision of AMGSSS development schedule.

would be demonstrated with an existing platform. The contractors would also develop preliminary concepts showing how their platform could be modified to support the AMGSSS concept to deploy up to three vehicles to remote sites. In Phase II, the most promising of the approaches would be selected for evaluation against AMGSSS-specific requirements. These included remote takeoff and landing, landing on slopes, autonomous flight, payload capacity, limited flight quality testing, and development of an AMGSSS-specific platform design. In Phase III, the contractor would integrate the payload packages with the platform and deliver three such platforms to the government for integration and evaluations with the Control Display Center. The BAA restricted the competition to vertical takeoff and landing craft using shrouded-propeller (or ducted-fan) designs.

Six proposals were received and three contracts were awarded for Phase I. The contracts were to Sikorsky for its Cypher, McDonnell Douglas for the DASS, and a team of Stratos and Moller for a version of the Moller Aerobot platform. McDonnell Douglas was awarded a Phase I contract even though its only vehicle had been destroyed in a crash. This award was made on the basis that the technology had been recently demonstrated, the design was simple and potentially low cost, and because the company indicated a willingness to construct a new vehicle for Phase II using internal company funds.

As of the end of FY 93, the Cypher Phase I flight demonstration had been completed. Although a videotape of a DASS flight was accepted as proof of the design capability of the DASS, McDonnell Douglas decided not to complete the Phase I tasking since it did not have an existing vehicle and was unwilling to build a new craft with company funds. The Stratos–Moller team Aerobot platform was demonstrated early in FY 94.

The Phase I demonstration flights indicated suitable technology existed on which to base an AMGSSS air platform design. The Sikorsky Cypher platform appeared to be the most advanced and came closest to being able to carry the necessary payload. However, it was apparent that further development would be required.

The remote operation concept studies of Phase I provided some assurance that air platform design modifications were feasible that would allow incorporation of the AMGSSS payload and remote landing, and takeoff as well as remote engine start.

As a result of the FY 93 investigations, the system concept and program plan were updated.

SUBSYSTEMS DEVELOPMENTS: FY 1994, PHASE II

During this year, studies, experiments, and designs were undertaken to finalize the AMGSSS subsystem approaches.

Air-Mobile Platform (See Appendix B for details.)

The original plan as outlined in the BAA announcement was to select two contractors for Phase II flight demonstrations and design work. However, reduced funding limited the selection to one contractor. Sikorsky was selected as the sole Phase II contractor since its Cypher vehicle was considered the most advanced and came closest to meeting the payload requirements of the AMGSSS mission. Limited FY 94 funding also did not permit acquisition or development of the payload subsystems as described in the program plan.

As a result of briefings by PSEMO within the Army, the Dismounted Battlespace Battle Laboratory, Ft. Benning requested a flight demonstration of the Cypher at the Commanders' Conference at Ft. Benning in May 1994. Therefore, that demonstration was included in the Phase II contract with Sikorsky. The demonstration was successfully completed leading to program support including the entry into the Army review and comment cycle of a draft Mission Needs Statement (MNS), prepared by the Dismounted Battlespace Battle Laboratory. The demonstration at Ft. Benning was also very useful in providing information concerning the Army's operating environment as well as user feedback on the AMGSSS design concepts.

Following the Commanders' Conference, Sikorsky's Phase II flight testing demonstrated advanced technical capabilities pertinent to the AMGSSS mission including the ability of the vehicle to land on and take off from sloped surfaces and to perform closed loop, controlled, hands-off takeoffs and landings.

Payload

Candidate sensors and communications equipment were evaluated in field experiments. Recordings were made of the video and infrared sensor output in a variety of scenes with and without targets. These were to be distributed to vendors to determine the capability of various sources to adapt their existing image-compression and target-motion-detection techniques to the AMGSSS mission.

Control Display Center

The systems control and display requirements were determined, and progress was made in developing control-display system concepts.

Technical Development Plan

As a result of the FY 94 investigations, the system concept was updated, and a technical development plan was formulated. The development program would bring the AMGSSS to a Milestone II decision point in 4 years.

MISSION PAYLOAD PROTOTYPE WITH CONTROL STATION: FY 1995, PHASE II (CONTINUED)

Limited FY 95 funding did not allow implementation of the plan. Instead, FY 95 efforts were focused on prototyping the mission payload, communications, and operator interface subsystems, which together were termed the Mission Payload Prototype (MPP). The MPP would provide valuable information on payload weight and performance and communications performance. Also, it would allow early input from the operators on the information the system provided.

Sikorsky was tasked to fly the Cypher vehicle with a mockup of an elevated sensor pod to evaluate the effect on aerodynamics of flight with a simulated AMGSSS payload package. Sikorsky also made progress in engine quieting.

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* For further information, contract the Adaptive Systems Branch, NCCOSC RDT&E Division, San Diego, CA.

APPENDIX B: DESIGN CONCEPT FOR AMGSSS AIR-MOBILE PLATFORM

(The following is taken from the Sikorsky AMGSSS Phase 1 final report. A number of these design concepts have been modified since that report was written.)

The AMGSSS air-mobile platform (AMP) is based on a modified Cypher unmanned vehicle. The Cypheraircraft is configured with two counter-rotating rotors shrouded by a fuselage that houses the aircraft's subsystems. The counter-rotating rotors counteract the gyroscopic forces and slip-stream rotation associated with single rotor and ducted fan configurations. The rotors incorporate cyclic and collective blade pitch controls to control vehicle motion. The toroidal shape of the fuselage is optimized to provide lift in hover and stability in forward flight. To enhance AMGSSS capabilities the mission sensors are housed in an elevated pod. The five major systems of the air vehicle are described below.

AIRFRAME ARRANGEMENT/STRUCTURE

The Cypher airframe is an all graphite composite reinforced structure consisting of the inner shroud ring, an outer shroud fairing, bulkheads, and support struts. The AMGSSS configuration adds to this airframe a spring landing gear and a sensor support tripod/platform. The inner shroud ring serves as the primary support structure for all aircraft subsystems, while the support struts serve as the primary structural link between the rotors and the fuselage. The bulkheads distribute local loads, such as engine and equipment weight, into the inner shroud ring. The airframe is sensitive to mass distribution and has been analyzed using finite element modeling to optimize its weight and frequency response. The fixed alighting gear is sized to absorb landing loads and does not incorporate any damping features, as the vehicle is unmanned. The fixed sensor mounting tripod supports the mission sensors and their directional control actuators.

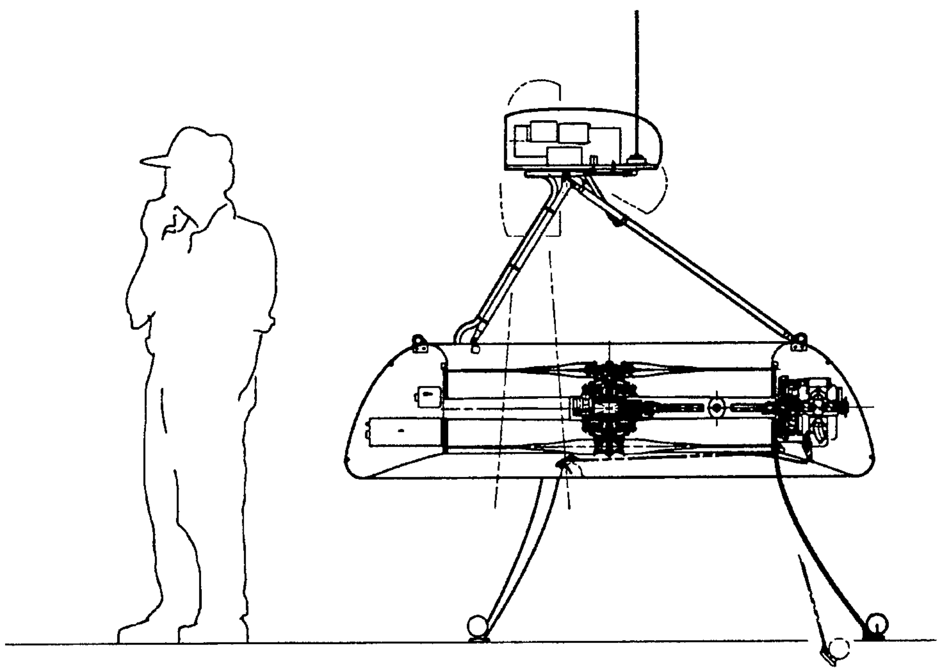

Figure B-1. Inboard profile view.

Both the alighting gear and the sensor tripod can be folded and retained on the vehicle when the Air Platform is stored on the AMGSSS trailer. This minimizes the amount of loose equipment. Lifting lugs are incorporated for ground handling operations.

PROPULSION SYSTEM

The rotor system of the AMGSSS AMP is based on a refinement of the present Cypher counter-rotating coaxial configuration. Sikorsky has been evaluating methods of optimizing blade taper and twist for the Cypher aircraft using computational fluid dynamics. Each of the two 4 ft. diameter rotors has four blades attached to a bearing-less flex beam. Full cyclic and collective pitch control is provided by a total of six electric servo-actuators.

For AMGSSS, a variation of the Cypher gearbox was incorporated to provide a gear ratio optimized for rotor and engine performance. A drive shaft with couplings at each end passes through one support strut and transfers power from the engine to the gearbox. An over-running clutch located between the engine and the drive shaft allows the rotor system to free-wheel in the event of an engine failure.

The AMP uses the 294 cc, Alvis Motors model NR801T rotary engine. This single rotor engine has been upgraded to incorporate electronic fuel injection, giving it the ability to produce 60HP at 8000 RPM. An electronic-inductive ignition system replaces the existing CDI unit and provides a dual spark through a weight-saving dual-ended coil. A combination of liquid and air cooling is used to cool the block and rotor respectively. Cooling of the water-glycol liquid is provided by a shroud mounted radiator. Fluid is circulated by a belt-driven pump.

The noise signature of the engine will be dramatically reduced by replacing the existing ejector with a low power loss, tuned, multi-chamber muffler. A centrifugal fan was added to replace the rotor cooling function of the ejector. Rotor cooling air will now be pumped through the engine via the belt driven centrifugal fan.

The fuel system consists of a single fuel tank with an internal electric pump which supplies the 100LL aviation gas to the engine. The engine will also operate on RON 94 or higher automotive gas.

ELECTRIC POWER SYSTEM

The AMGSSS air vehicle operates on two voltages: 28VDC as supplied by the starter/ generator, and 12VDC as supplied by DC-DC converters.

The generator system supplies a minimum of 1200 Watts of 28VDC $\pm 10\%$ over a range of 5000 to 8000 engine RPM. Power is supplied as long as the rotors are turning above the generator's minimum speed, regardless of whether the engine is running or not.

An upgraded power control unit is incorporated to supply power to the starter and to condition the power coming from the generator. Power to drive the starter is supplied by onboard batteries when at a remote site, or by an externally attached umbilical cord from the support trailer when the air vehicle is at the ground station.

The AMP on-station electrical demands will be satisfied by a multi-cell battery package that is sized to support twelve hour duration missions and associated part-time sensor activity while running to exhaustion by the close of a mission. The results of the Phase I Mission Power Source Trade indicate this energy storage component supports a twelve hour mission scenario and nominal use of the

electro-optic sensor equipment, not to exceed about thirty minutes of total use out of every hour of on-station performance. Conducting Seismic and Acoustic background surveillance has been considered a continuous operation for every hour of battery discharge.

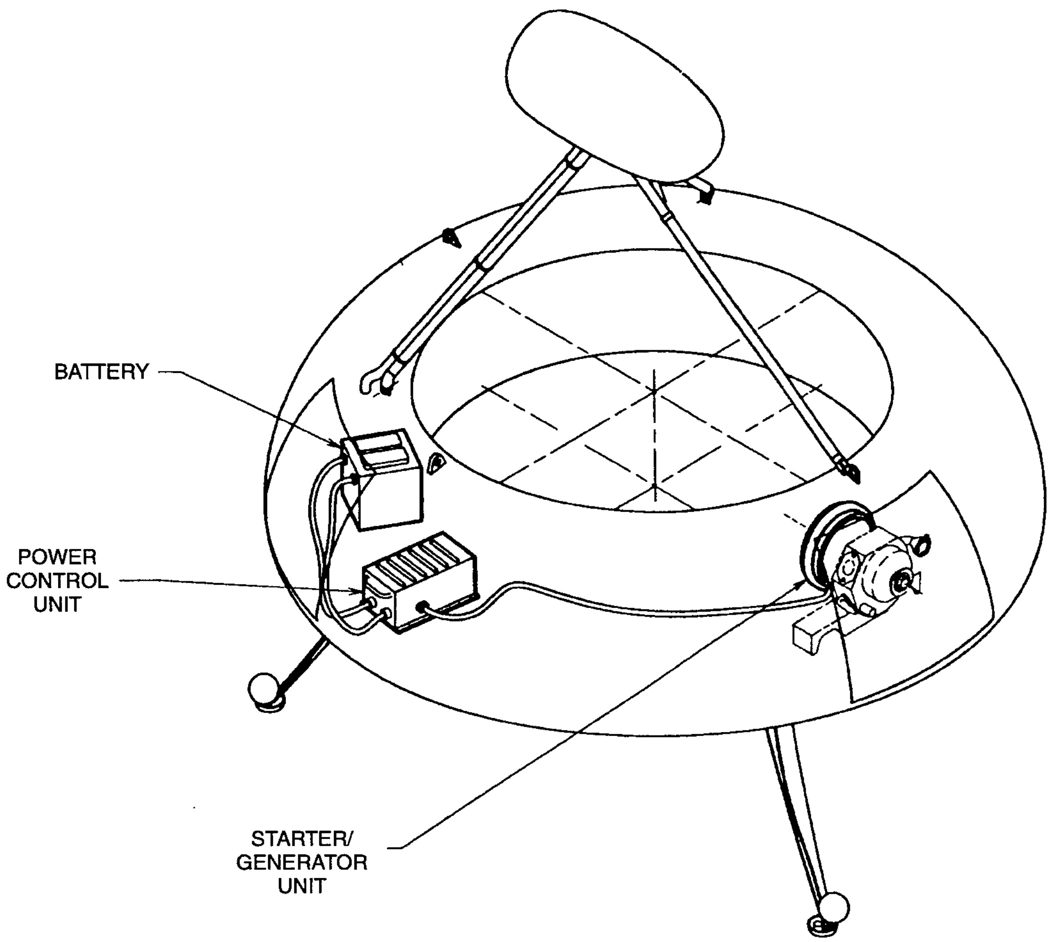

Figure B-2. Start system.

ALIGHTING GEAR

A simple spring-style gear is mounted to the structural inner shroud ring providing energy attenuation upon landing and elevating mission sensors for enhanced performance. The tripod configuration is stable in all situations and will support the AMGSSS air-mobile platform on sloped landing sites up to 30 degrees.

Foot pads, illustrated in figure B-3 are used to minimize ground loads, and also serve as mounting platforms for seismic and acoustic mission sensors. Spring loaded pivots for the pads reduce loads on the sensors, and provide the mechanism for 'weight-on-wheels' sensors which are used to assess excessive landing site slope.

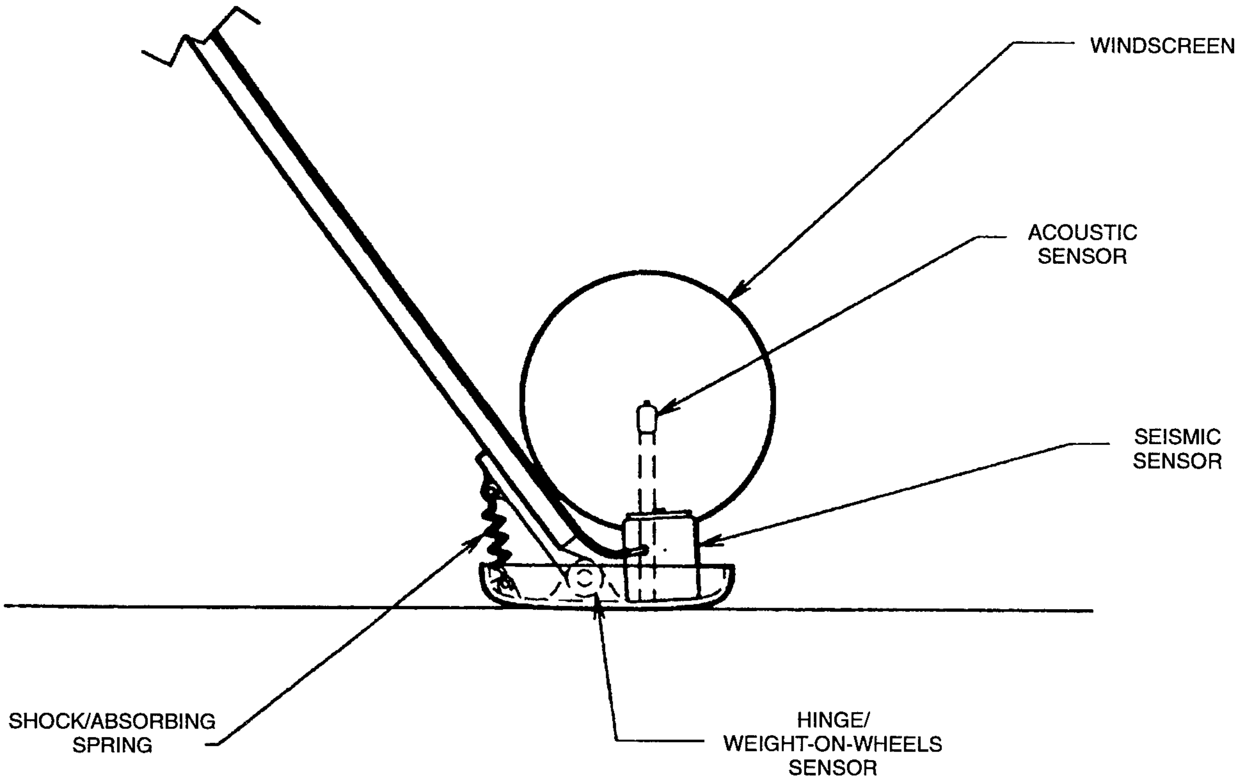

Figure B-3. Landing gear foot pad configuration.

Acoustic and seismic sensors are mounted on the feet of the landing gear. The seismic sensor requires good contact with the ground for optimal function. One seismic sensor is provided per air vehicle. The acoustic sensors are mounted low to the ground to reduce their susceptibility to wind noise, and to provide the widest possible spread of the microphone array. One microphone is located on each of the three landing gear feet.

Non-structural hinges allow the three legs to be folded for storage. Captive fasteners are used throughout, and no disconnecting of wires is required due to pigtail loops located at the hinge points. Foot-mounted sensors are protected from damage since they are within the surrounds of the shroud. Figure B-4 illustrates the method of folding and unfolding the AMP landing gear.

AMGSSS MISSION SENSOR INSTALLATIONS

Visual sensors (infrared and video) are mounted on a gimbaled platform which is supported by a tripod arrangement above the vehicle body, and covered with a fairing. Sensor height is comparable to that of a man's eye, roughly six feet. The azimuth of the platform varies from ± 180 degrees, and is driven by an electric motor through a reduction gear. Platform elevation is driven via a screw jack mounted to the tripod, and has a range of +30/–90 degrees to allow for a variety of sloped terrain. As illustrated in figures B-5 and B-6, the AMGSSS sensor installation supports 30-degree slope landings and landing site assessment utilizing a single set of sensors. An electronic compass and inclinometer are mounted on the platform to give the operator spatial orientation cues regardless of the position of the body of the vehicle.

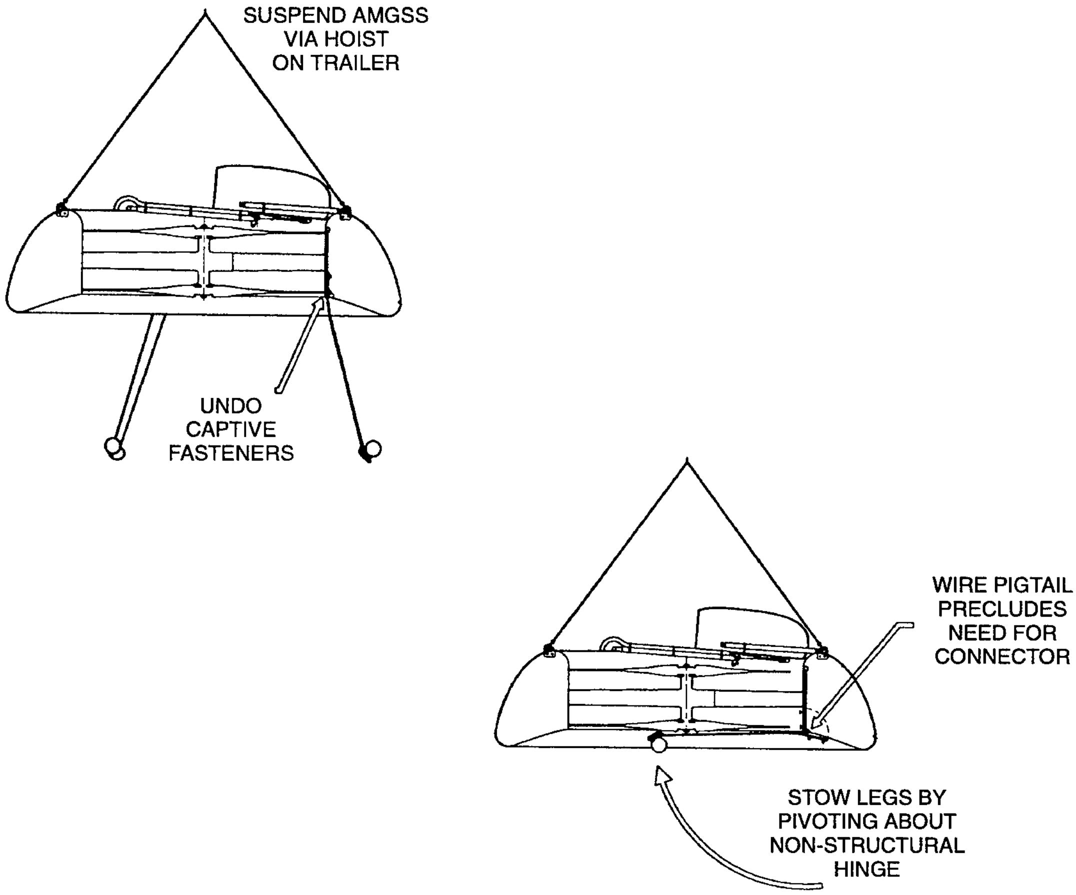

Figure B-4. Landing gear fold/unfold sequence.

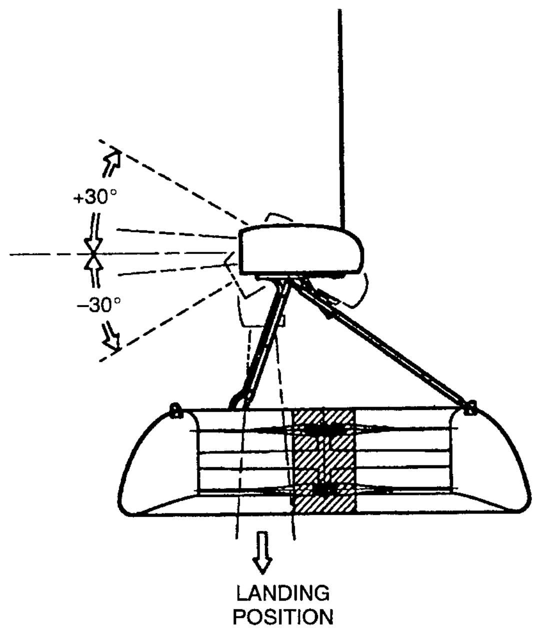

Figure B-5. Landing site assessment pod position.

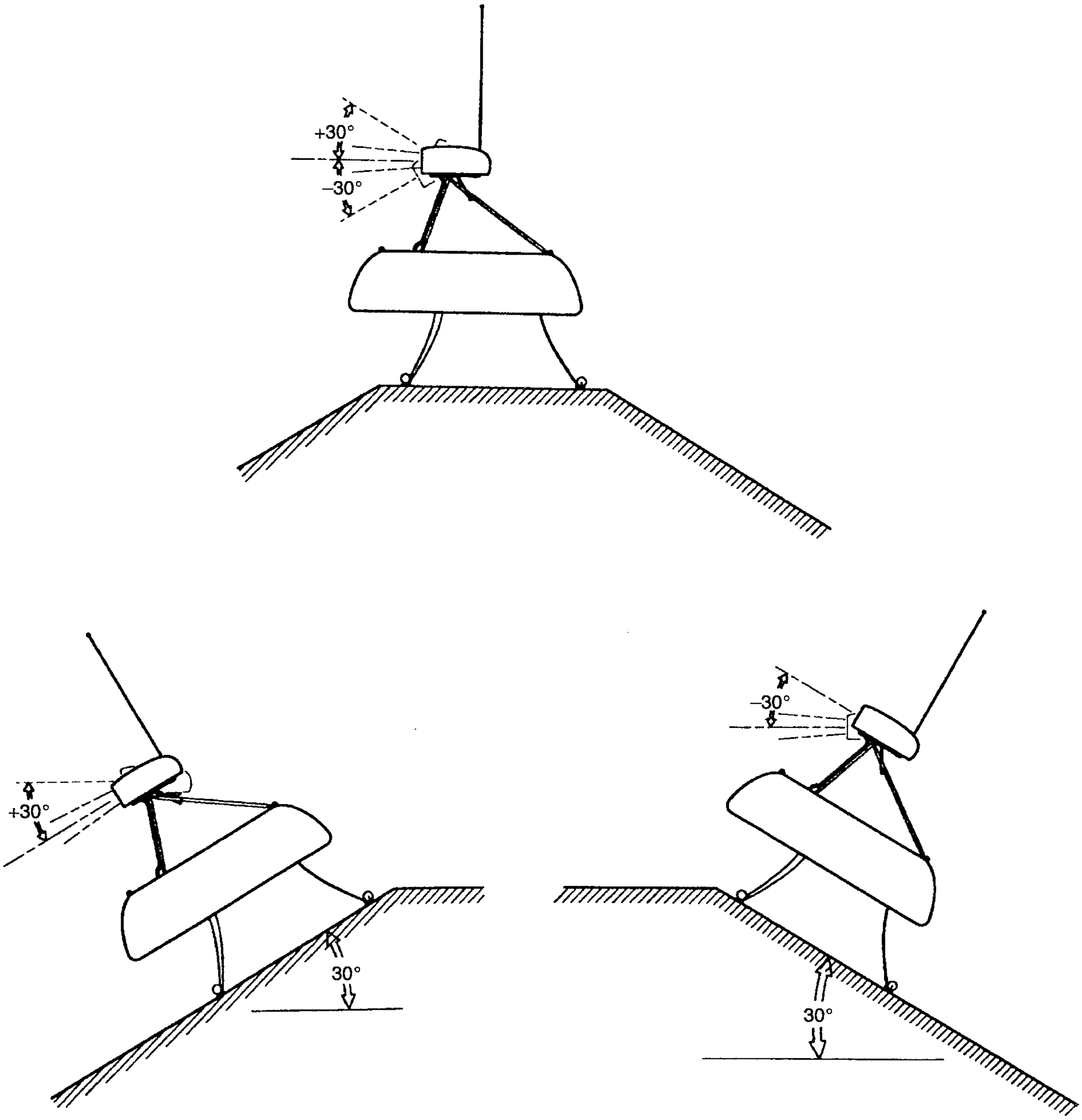

Figure B-6. Slope landing capability.

The sensor pod has the ability to look straight down, allowing the primary mission sensors to be used for assessing potential landing sights in any ambient condition. It can also be rotated backward during flight to protect the sensor windows from damage.

The pod does not rotate more than half of a revolution during an azimuth scan, eliminating any requirement for slip rings. Scan rates are more than sufficient (360 deg/10 sec), given the limited transmission rate of the available non-line-of-sight data link.

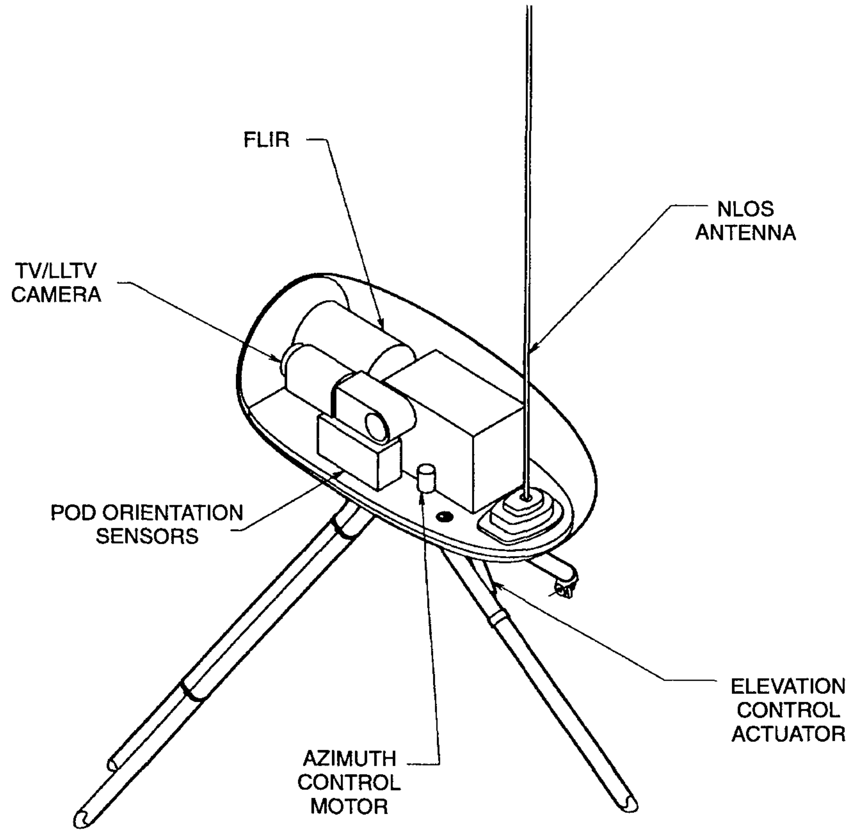

Figure B-7. AMGSSS pod interior arrangement.

The tripod support legs are provided with hinges and quick-release pins to allow the pod to be folded for storage. No electrical connectors need be disconnected due to a pigtail loop at the hinge point of the tripod struts. Struts are retained by the quick release pins and dedicated fittings. The non-line-of-sight antenna must be removed for storage.

AIR VEHICLE AVIONICS

The avionics architecture of the Cypher air vehicle, as currently configured, is able to meet all of the AMGSSS flight requirements with just a few modifications and/or enhancements. Figure B-9 illustrates the AMGSSS/Cypher system architecture. (The equipment labeled "Cypher-Specific" on figure B-9 will be removed for AMGSSS; it is not essential for the mission.)

Navigation

The basic navigation hardware configuration of the Cypher air vehicle supports all of the AMGSSS requirements. Due to degradation in accuracy of selective availability, however, replacing the C/A code GPS with a P-code GPS will enable the air vehicle to maintain a position hover and fly a specified flight path more accurately. In fact, in order to meet the 10-meter positional accuracy requirement, use of P-code GPS is required.

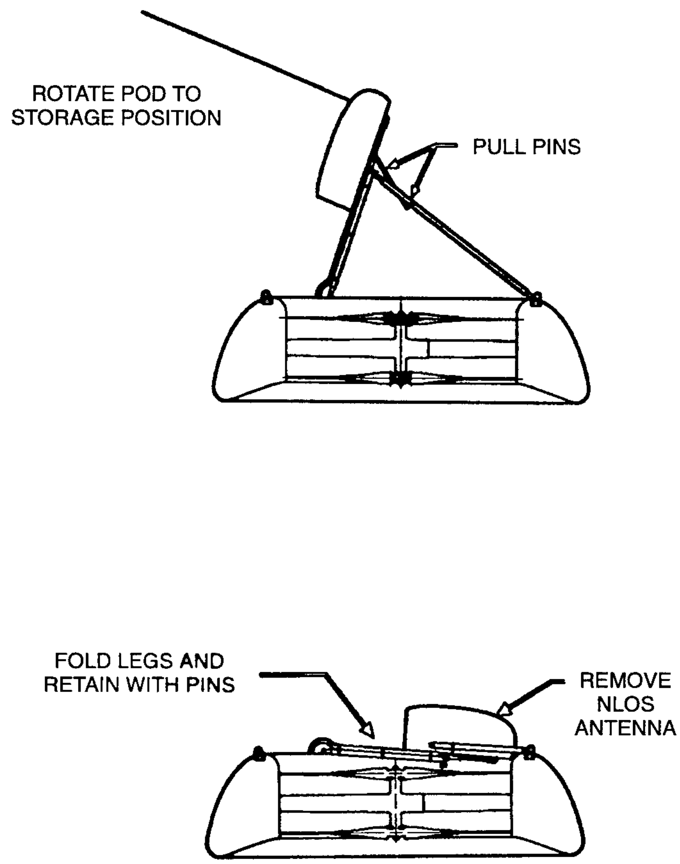

Figure B-8. Sensor pod fold sequence.

The Honeywell In Flight Management Unit (IFMU) navigational processing includes the capability to generate a flight path between two specified points. It furthermore contains the ability to determine the perpendicular distance the air vehicle is from this flight path. When this capability is coupled with the flight control system, a positional error of zero is automatically maintained. Using a proportional calculation, the air vehicle's heading can be changed according to how far off course the air vehicle is, thus automatically accounting for sensor drift and wind drift.

An enhancement to the basic navigation capability will be addition of the waypoint database. Instead of a single way point and a single flight path generation, the navigational software will receive a set of way points. Thus, as each way point is overflown, the IFMU will calculate the next leg and associated heading.

Vehicle Management

To perform the AMGSSS mission, the auto-takeoff and auto-landing functions, way point navigation, and contingency plan functions are required.

From flight testing it is known that the stability of the air vehicle and low center of gravity makes it possible to command a preset altitude scheduled descent rate in support of auto-landing.

Incorporating knowledge of contact with the ground (using weight-on-wheels type of switches) enables a sloped landing using this same simple approach.

REFERENCE

B-1. "Phase I Final Report for (AMGSS) Air Mobile Ground Security System," 17 November 1993. SER-CY001, Contract N66001-94-C-6007, UAV Technologies, Sikorsky Aircraft Division, UTC, Stratford, Connecticut.

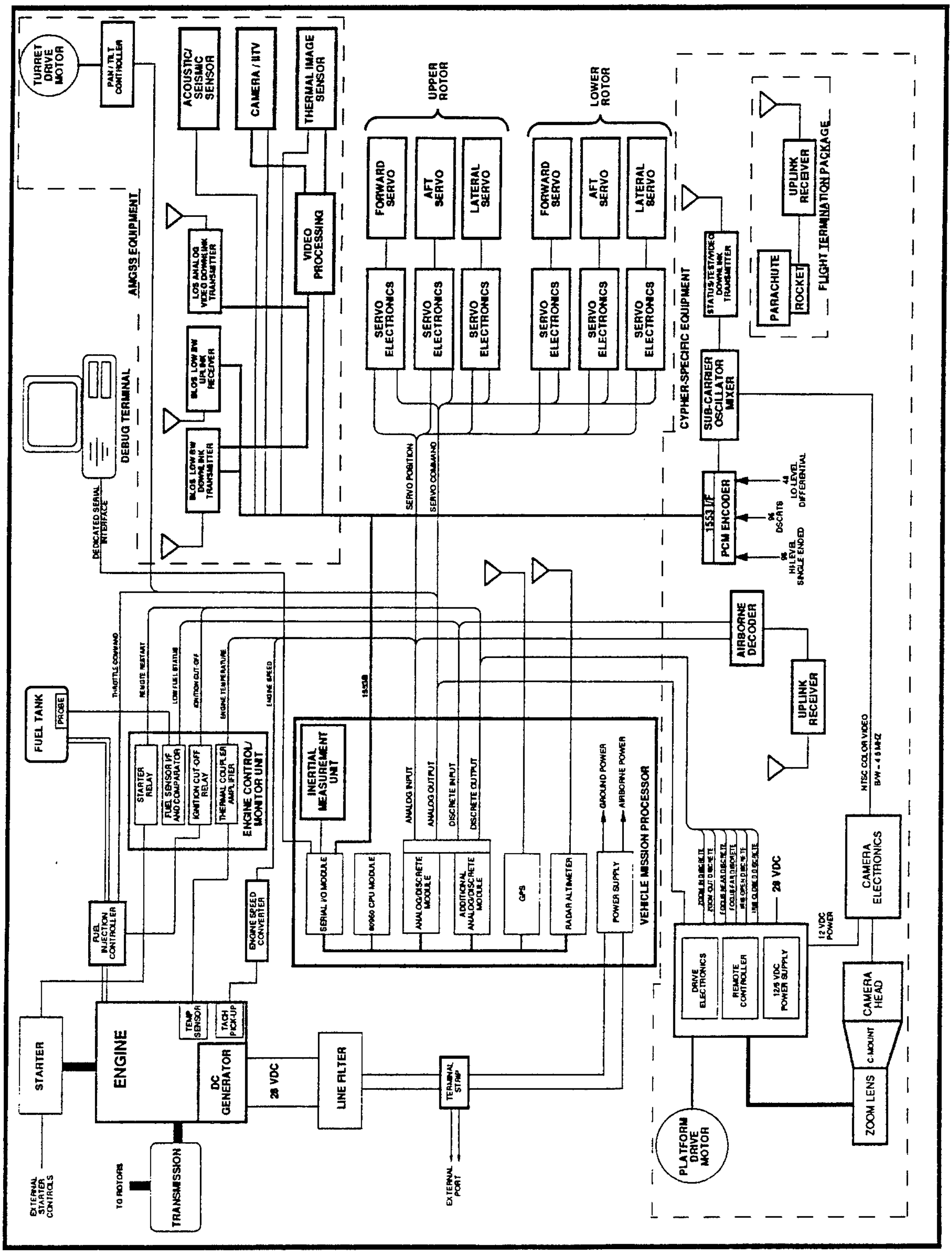

Figure B-9. AMGSSS system architecture.

APPENDIX C: COMMUNICATIONS

Brett Martin

REQUIREMENTS

In 1993-1994, the following requirement specification—arguably a "wish list"—was established for the AMGSSS radio communications subsystem.

Very Reliable Low-Rate Communications for Vehicle Control

The radio communication system will provide the base station with wireless control capability. Commands are sent to the mobile unit and status messages are returned to the base station. A data rate of 600 bits per second is adequate for this task. Latency must be low—preferably less than 1/10th second— to maximize the control capabilities of the base station. Although the air vehicle is designed to react safely and predictably in case of communications loss, clearly this type of situation should be avoided.

High-Speed Data Communications

The mobile unit is capable of sending large quantities of image data. Ideally, the data communications rate should be around 100 kbits per second; this allows the operator to receive image updates nearly every second.

Ability to Transmit over Terrain without a Repeater

In the ideal deployment scenario, communication services are handled directly between the mobile units and the base station. If a relay or repeater were required, an additional resource—such as another AMGSSS mobile unit—would be required.

10-km Range

Ideally, the range of the mission should not be limited by the range of the communications system. A range of 10 km is viable for the mobile unit; this value was chosen to limit the weight of the fuel to an acceptable amount. Therefore, the communication system should provide reliable control and data transfer at a 10-km range.

Low Weight

The weight capacity of the air vehicle is severely constrained. As the radios get lighter, the weight capacity for batteries increases. With greater battery capacity comes the option of greater transmitter power. Therefore, the lighter the radios, the higher the transmit power and the greater the range. A radio subsystem weight of 2 lb (excluding batteries) would be viable.

Low Power Consumption

Although the efficiency of a radio transmitter is determined primarily by the frequency band and waveform, the power consumption of a radio receiver is determined by many design parameters. For this application, the receiver should be designed for a power consumption of under 1 watt.

Small, Light, Omni Antenna

Practical packaging constraints of the air vehicle prevent the usage of whip antennas over 1.5 m, rotators over 0.5 lb, and directional antennas of length or radius greater than 0.3 m.

Compatible with Current Frequency and Protocol Usage

Since this system is intended to be used as a part of actual military missions, it must not interfere with other communications activities. The frequency allocation and usage must be compatible with standard and approved military communications systems that are or will be operating in the same frequency band. Ideally, fielded communications systems would be used to simplify logistics, training, and maintenance.

Compatible with Commercial "PC" Hardware and Software

Commercial "PC" computer hardware and software is used in AMGSSS. The data interfaces of the radio communications subsystem must be compatible with the appropriate interfaces in the AMGSSS payload.

Non-Developmental and Low Cost

The AMGSSS program has not possessed the amount of funding required to develop a fieldable communications system. We have constrained the cost to $15,000 per "side" of the communications link.

OPTIONS CONSIDERED IN 1994

Choice of Frequency Band

The appropriate frequency band was determined by the two primary constraints: antenna size and the requirement for direct transmission over terrain. The 30-88 MHz tactical band is clearly optimal. At lower frequencies, the decrease in antenna efficiency and increases in noise levels reduce the signal-to-noise ratio. At higher frequencies, the attenuation from hills and terrain more than supersedes the gains made by the greater efficiency of the mobile antenna and the added gain of the base station antenna. This "tactical band" is used by the Army and Marine services for these same reasons.

Choice of Hardware

Radio. Radio transceivers used in commercial applications do not operate over such a broad range of frequencies, since it would not be possible to obtain a license for such operation. Therefore, the only non-developmental wideband transceivers radios on the market are intended for military applications.

At 10 to 15 lb, manpack radios are far too heavy, given the limited payload capacity of the air vehicle. Aircraft radios are also heavy, and they are not designed for low power consumption. We were limited to hand-held tactical radios that could operate in a data mode. Of the world's hand-held tactical band military radio production, there were none that could transmit data rates greater than 2400 bits per second. However, Racal Communications offered a prototype—a modification of a production radio—that could transmit at 16 kbits per second using the military standard radio modem, the Tactical Communication Interface Module (TCIM). Initially, we tested a prototype with

a 9800 bit per second RS232 interface; this unit could be operated with any notebook computer. However, we chose to buy the synchronous 16-kbit version of the radio instead for the virtues of the higher data rate and compatibility with the other tactical radios currently in the field (such as SINCGARS). Unfortunately, Racal had not tested this version of the radio; we were the first customers. Nevertheless, we decided to accept this additional degree of risk.

Computer Interface. The TCIMs currently in the field are configured as ISA standard interface cards. These are not suitable for our application, because they consume several watts and, even more importantly, require the usage of a particular SCSI interface module that is no longer in production. During 1994–1995, Magnavox was preparing to produce a PC Card (PCMCIA) version of the standard TCIM. They loaned us a couple of prototypes to use during our development period. These units interface PC computers with PC Card ports (which is becoming the standard configuration for commercial notebook computers) with tactical radios. The PC Card TCIM is not compatible with the SCSI TCIM software that has already been developed (by SAIC). Since low-level TCIM software development is complex and difficult, we did not think it to be within the scope of our effort. However, Magnavox gave us the source code for their own demonstration software, and we were able to integrate this code into our specific application.

RESULTS FROM DEVELOPMENT WORK THROUGH 1995

Choice of Frequency Band

The characteristics that we predicted for 30-88 MHz radio propagation proved to be fairly accurate. Using SINCGARS radios and mediocre antennas, we were able to communicate reliably over hills of 500 feet at distances of 2 to 3 km. The maximum range that we could achieve at our hilly Point Loma site was 5 km. We did not have the opportunity to test the range over an open field to verify that 10 km was possible.

Choice of Data-Transmission Method

The combination of the TCIM, tactical radio, and modified demonstration software proved to be usable and functional, but too idiosyncratic for field usage.

- Certain types of data errors would cause complete loss of the communication link, and the link would require a manual reset. We could not duplicate the failures we experienced in the field at Magnavox's facility. Occasionally, data errors did occur despite the existence of error correction algorithms that should have made such errors impossible. Clearly there is a need for greater refinement in our software.
- The "error free" two-way radio link through a single radio frequency created an immense amount of data overhead, software complexity, and many degrees of freedom for errors to occur. (The single channel TCIM and accompanying software did not provide us with the option to use full duplex.) A high percentage of the total transmission time was spent by the radios merely exchanging blank or status messages in order to maintain the continuity of the link. Approximately 45 seconds were required to initialize the link—an excessive amount of time for in-flight link initialization.
- The effective data rate was 2000-4000 bits per second. Certain operations became agonizingly slow. We could double the data rate if we had a proper scrambling algorithm for ensuring 33% bit transitions. As of this writing, Magnavox has not yet completed this algorithm.

- In many locations, it was not possible to establish a reliable radio link, although it appeared that such a link should be possible. We blame the terrain and antenna characteristics for these problems.

Choice of Radio

There are many subtle characteristics of the Racal radios that are different from those of a SINCGARS radio. Although these differences could be corrected in our software, it is clear that the two radios are not truly compatible. It is possible that Racal's new Leprechaun radio (prototypes are projected to be available in Spring of 1996) will resolve these compatibility issues. Of greater significance is a technical defect: The case and data port are effectively unshielded, and radiation from the host computer enters the radio with enough energy to reduce the effective maximum sensitivity by several orders of magnitude. (The host computer operates within the 30-88 MHz band and emits a considerable amount of energy. Even if the computer was shielded, this energy would travel down the bus, into the TCIM and finally into the radio.) As a result, the range of the Racal radios is considerably less—1/4 to 1/10th the range of the SINCGARS when transmitting at equivalent power levels with equivalent antennas.

OPTIONS AVAILABLE FOR 1996

Changes in Tactical-Band Radios

The design of new production SINCGARS radios is being updated. New features include RS232 ports and built-in data correction. As a result, it is no longer essential to use a TCIM for data communication.

ITT is selling a SINCGARS portable radio. Unlike the Racal unit, it includes RS-232 ports as well as MIL-STD 188-114; frequency hopping; COMSEC; and a remote control capability. Unfortunately, it weighs 4.9 lb (with battery). This unit should be seriously evaluated before the purchase of any additional Racal radios.

Changes in Other Wireless Technology

Wireless Local Area Network (WLAN) hardware is becoming a rapidly growing industry. This technology is sold to industry as a low-cost method of expanding widely separated LAN nodes. Equipment is available in the unlicensed 902- to 928-MHz and 2.4-GHz band. Very small components can be used to build the 2.4-GHz WLAN hardware, and chipsets for PC Card (PCMCIA) construction are available. For the AMGSSS application, each surveillance vehicle would be equipped with a 902- to 928-MHz WLAN transceiver. The repeater would be capable of receiving signals from each surveillance vehicle and multiplexing the data onto a wider bandwidth 2.4-GHz link to the base station. The primary design risk in building this system involves the potential interference between the multiple 902- to 928-MHz WLAN units. Since many different modulation types and models are available—fixed-frequency, direct-sequence spread spectrum, and frequency-hopping spread spectrum—a viable solution is undoubtedly available.

Satellite

Low Earth Orbital (LEO) satellites would be an attractive option for AMGSSS. Although several companies are in the process of implementing a commercial system of this type, it will be several

years before it is available. Geostationary satellites require more transmitter power (or a larger antenna) than is possible with the AMGSSS vehicles.

CONCLUSIONS

Virtues of VHF-Tactical-Band Approach

The fundamental question concerning the design of the AMGSSS communications subsystem is, "What frequency band should be used?" If the tactical VHF band is used, then:

- Repeaters need not be used if the surveillance units are landed in appropriate places.
- Standard tactical radios and associated equipment—items in the field that are available, supported and understood—may be used.
- Standard data security procedures may be used.

Vices of VHF-Tactical-Band Approach

- The data rate is low.
- The standard equipment in the field is outside of the control of AMGSSS. As a result, actual performance and reliability may not be as good as expected.
- The TCIM requires special and complex software. The cost and support of special software will be necessary for AMGSSS.
- Actual range and performance is difficult to predict in real scenarios. Although it is possible to transmit successfully over hills and terrain, it is easier to fail in this effort.
- The computers operate in the same frequency band as the radios. Radiation from our computers—which is essentially broadband noise from 8 to 50 MHz—significantly reduces the ability of the Racal radios to receive weak signals. Attempts at shielding the computer itself were unsuccessful, since the majority of the radiation entered through the digital interface. Magnavox does not employ any filtering in the PC Card TCIM. SINCGARS radios do have effective shielding at all ports, and we had no reception problems when these radios were used.

Virtues of Commercial UHF Equipment Approach

- High data rates are possible.
- All equipment could be specified and controlled by the AMGSSS program.
- Little custom software would be required. All low-level functions are embedded in the hardware.
- Direct-sequence spread spectrum capabilities provide excellent data security and low probability of detection.
- This type of hardware is sold primarily to business customers. Wireless Local Area Network (WLAN) hardware is becoming a rapidly growing industry.
- Very small and lightweight hardware is readily available.

Vices of UHF-Band Approach

- The use of a repeater would be essential in most circumstances. Although there are several possible alternatives, the most versatile approach would use one AMGSSS vehicle dedicated to repeater usage. (Since this vehicle would, by definition, be located above the others, it could also be used to track a target once it had been detected by another AMGSSS vehicle at a closer range.)
- Very little standard military equipment could be used.
- There is a potential for frequency allocation conflicts when used with other military operations.
- The radio signal would attenuate to a very low level if an obstacle were placed in the radio path. Therefore, a failure in the repeater would probably cause a complete loss of operation. In order to prevent a complete loss of the hardware in this type of circumstance, a HF or VHF backup radio system must be included in all vehicles.
- Transmitters in this frequency range are typically fairly inefficient, and therefore the maximum available transmitter energy is less than that of a VHF system. However, the usage of the repeater and a high-gain base station antenna will extend the range of the system to the required levels.

RECOMMENDATIONS

In 1994, the tactical radio approach seemed to have the most merit: The capability of maintaining a radio link without maintaining line of sight was considered to be of paramount importance; the standardization of SINCGARS was very attractive; and the usage of existing military communication protocols very practical. In practice, a predictable radio link was found to be more valuable than a versatile one; the lightweight SINCGARS substitute was not a strong performer; and the existing protocols were found to be inappropriate for our application.

We could improve our tactical radio system by adding another radio to create full-duplex; utilizing the new dual-channel PC Card TCIM from Magnavox; fixing the shielding problem with the Racal radios; changing our communications architecture to one that can reliably handle data errors gracefully; and completely changing the radio control software. If these changes were made, the data rate would increase to 6000-8000 bits per second; no link initialization would be needed; and the latency would decrease by an order of magnitude. However, the actual effects of real hills would still be somewhat unpredictable, and the data rate would still be a fraction of our true requirements.

Therefore, a change to a wireless (UHF) LAN should be seriously considered. This approach would require a repeater in most circumstances, and this does create some practical disadvantages. However, the virtues of a predictable link, straightforward software, and a high data rate seem to be more important factors when the system is actually used. For in-flight operation, a VHF backup receiver should be used, but this would not add significantly to the overall weight of the payload.

I recommend that we do a market survey to determine the best candidates for wireless LAN transceivers. Then, we should try them and uncover problems of which we are presently unaware. If this approach performs well in the field, then I suggest that these wireless LAN units replace the current tactical radio system. However, it may be desirable to retain the current tactical radio system hardware for in-flight backup communications.

APPENDIX D: SENSOR SUITE

Jeff Coleman

The sensor suite must be able to view designated (in azimuth and elevation) sectors or all of the terrain surrounding a deployed system. The sensor subsystem must detect vehicular traffic or dismounted soldiers in the designated sectors to ensure they do not penetrate a protected area undetected during both day and night operations and under a variety of weather conditions. The sensor suite must be capable of detecting and identifying ground vehicular targets at 2500 m and personnel at 1000 m during day and night operations. The suite must also determine range of targets when commanded by the operator. The video sensors must be mounted on a pointing device that allows unrestricted observation of the terrain surrounding the deployed system; the pointing device must also provide feedback indicating the direction the sensors are pointing. Because video sensor operation and video communications generally require relatively large amounts of continuous power and battery operation is desired, all components must be low power. An acoustic capability is an optional sensor, and must be capable of detecting vehicles at long range and indicating direction for camera pointing.

VISUAL IMAGING

Requirements

The daylight visual imaging system is required to provide high-resolution monochrome images with sufficient resolution to allow classification of vehicles at 2.5 km and personnel at 1 km. For initial panorama capture, a zoom lens with at least a 16-degree image width at the wide setting is required.

For target detection, the well-known Johnson Criteria (reference D-1) for classification of personnel or vehicles on still images translate to a requirement for an 8-pixel minimum dimension. Assuming the worst-case target to be a man 0.7 meter wide at 1 km, the image will subtend 0.04 horizontal degrees. If this meets the 8-pixel requirement, a 500-pixel-wide imaging chip would cover 2.5 degrees. Thus, a maximum of 2.5 degrees is required at the highest zoom power if the imager provides at least 500 pixels horizontally. High sensitivity, dynamic range, and signal-to-noise ratio are also necessary to enable reliable long-range detection of targets.

Options Considered

There is no shortage of video camera manufacturers that offer cameras meeting AMGSSS requirements. Kodak high-resolution cameras were rejected as being too heavy. Sony and Cohu were the main companies considered, with Cohu finally selected.

Canon and Fujinon zoom lenses were considered to be readily available and capable of meeting AMGSSS lens requirements.

Analysis

The Cohu 2100 series camera weighs 6 oz., has 768(H) by 494(V) picture elements, electronic shutter, 20-dB AGC, >55-dB signal-to-noise ratio, C lens mount, auto iris output, 0.65-lux sensitivity at full video, 3.6-W maximum power, –20° to +60°C operating temperature, and shock tolerance of 30 Gs with 11-ms duration in all three axes. The package is small and output is RS170. These specifications meet all of the requirements and provide safety margins.

The Canon J10X10REA-IAII zoom lens with the Cohu camera provides a field of view of 3.7 horizontal degrees at full zoom. Combined with a 2X range extender, the field of view becomes 1.9 degrees, which meets the worst-case detection requirements.

Conclusions and Recommendations

The Cohu 2122-1024 camera with the Canon J10X10REA-IAII zoom lens and a 2X range extender meet all AMGSSS requirements for daylight video.

THERMAL IMAGING

Requirements

The thermal imager must meet the same requirements as the visual imaging system but in total darkness. A dual-field-of-view lens is preferable to facilitate observation of a larger area, but at a minimum, a single long-range lens is required. Thermal sensitivity of 0.1 °C or better is required at the ranges specified. Empirical testing of cameras has demonstrated that thermal imagers of lower sensitivity are difficult to use at ranges greater than 1 km.

Options Considered

Various options were considered for the thermal imager (reference D-2). Image intensifiers were considered as an option. Mid-wave versus long-wave infrared imagers were debated. Finally, all manufacturers of thermal imagers were contacted, and products were evaluated.

Conclusions and Recommendations

The Inframetrics InfraCam with a 100-mm lens was selected. This imager uses a platinum silicide focal plane array for high uniformity and a proprietary Stirling cycle dewar cooler to combine light weight with low power and reasonably high image quality. The lens is a compromise to combine availability, long range, light weight, and low cost while not narrowing the view too much for panorama gathering. A dual-field-of-view lens would be preferable, but may add $20,000 to the cost and 5 lb or more to the weight, depending on many tradeoffs. See reference 2 for more information.

LASER RANGING

Requirements

To determine the range of targets, a laser rangefinder must be included in the sensor suite. Minimum requirements are capability to reliably determine the range of typical military targets at up to 2,500 m with 10-m accuracy. Unit must be class 1 eyesafe and remotely controllable.

Options Considered

About 30 reported vendors of laser rangefinders were contacted and options were narrowed to the following nine models (table D-1).

Table D-1. Vendor comparison of laser rangefinders.

Model	Price ($K)	Max Range (km)	RS232	Weight (kg)	Other
Melios	25	10	no	1.8	8300 shipped to Army
Litton Mark VII	30–50	20	yes	1.6	GPS, I^2 scope, compass
Contraves	43	4	yes	0.6	2 built thus far, 20 in process
LSDI	23.9	5	yes	1.85	
ALST ELRF-2	22	10	no	1.8	better than Melios
SADT Teleranger	7.3–8.8	1.2–2	yes	0.9	
LTI	7.5	0.8–2	yes	1.8	
Laser Atlanta	5.5	0.61	yes	1.9	compass
Riegl Laser Tape	5.7	1.2–3	yes	0.9	

Notes:

a. Max Range is only a rough indication of range capabilities against non-cooperative targets. Different vendors use different measuring techniques and different target reflectivities.
b. This chart only includes long-range rangefinders.
c. SADT Teleranger price depends on accuracy. Lower price is for 5-m accuracy and resolution; higher price is for 1-m accuracy and 0.5-m resolution.

Analysis

Comparisons are easily made by referring to table D-1. Any of the first five units listed meets the range requirements. The Contraves unit is significantly lighter than any of the others, so Contraves may be the ideal unit. However, the Contraves price is the highest, and availability has yet to be proven. The Melios has the best proven track record in the military. But if range requirements can be relaxed, one of the last four rangefinders in the table may be ideal. The AMGSSS Mission Payload Prototype successfully incorporated a Reigl Lasertape. It was found capable of measuring ranges of 500 to 1000 m against most targets during the day, and up to 2600 m at night.

Conclusions and Recommendations

A Contraves laser rangefinder is recommended if the high cost is not prohibitive (or the price has dropped), and units are available. Alternatives include the Reigl Lasertape, if shorter ranges are sufficient, or the Melios, if long range is required. Since the market is rapidly evolving, vendors should be contacted again at the time of procurement and new developments evaluated.

AZIMUTH-ELEVATION MOUNT

Requirements

The azimuth-elevation (or pan/tilt) mount must be capable of pointing the video camera, thermal imager, and laser rangefinder in any azimuth direction (± 180 degrees) and ± 30 degrees of elevation. This equates to nearly 10 lb of payload. It must be capable of holding its position without

vibration and with little power consumption. Minimum angular speed should be 60 degrees per second in azimuth, 30 degrees per second in elevation.

Options Considered

Many azimuth-elevation units were considered, but none met AMGSSS weight, payload, speed, and power requirements (reference D-2). Discussions were held with Orbit Advanced Technologies, Inc. (215-674-4220), with News/Sports Microwave (619-670-0572), and with Transitions Research Corp. (203-798-8988) regarding modifications they could make to their units to satisfy our requirements. Finally, it was determined that the Transitions Research Zebra model came the closest and could be most easily modified to carry the AMGSSS payload.

Analysis

The Transitions Research Zebra model has a lower specified payload capacity than AMGSSS requires and can require high position holding power. Both problems were resolved by modifying the pan/tilt head, lengthening the shafts, and adding a custom camera mount that balances the payload around the pivot point. This keeps holding torque to a minimum, requiring little power. It was still necessary to operate at one fifth of maximum speed (still meeting AMGSSS speed requirements) to avoid overloading the motor controllers. Feedback is through a relative-position encoder, but absolute position is calculated by panning and tilting to the stops during system initialization.

Conclusions and Recommendations

The Transitions Research Zebra model with NRaD modifications meets the needs of AMGSSS and is recommended.

ACOUSTIC SENSOR

Requirements

The acoustic sensor is required for vehicular target detection and camera pointing in areas that may not covered by the field of view of the camera. It must be acknowledged that acoustic capabilities will be highly dependent upon the operating environment. Factors such as wind, thermal gradients, and background noise will dominate the system sensitivity. Nevertheless, given near ideal conditions, the acoustic sensor should be capable of consistently detecting operating military trucks at ranges up to 1 km and provide azimuth information accurate to ±6 degrees.

Options Considered

Section 4.2.2 in reference D-3 lists all makers of acoustic sensors considered. Acoustic sensor data sheets are available separately.

Analysis and Developments

Northrop, Lockheed Sanders, and Alliant Techsystems demonstrated working acoustic sensors. Since none of the sensors met the form factor and functionality requirements of AMGSSS without some modification, and the final form would be dependent on the vehicle, which was still not available, it was decided not to select and acquire a specific unit for the Mission Payload Prototype, but to incorporate an RS232 interface for an external sensor. This allows any vendor to demonstrate its unit

in conjunction with AMGSSS tests and minimizes development costs for the temporary configuration. The Northrop unit was made available and successfully tested.

Conclusions and Recommendations

Final selection of an acoustic sensor will depend on the AMGSSS vehicle. Until then, flexibility can be maintained through incorporation of an extra RS232 serial interface for communication with any acoustic sensor system. Several candidates are available, and none has been selected at this time.

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D-3. "FY 93 Technical Summary: Air-Mobile Ground Surveillance System (AMGSS) Project," 1993. Naval Command, Control and Ocean Surveillance Center RDT&E Division, Advanced Systems Division, San Diego, CA 92152–5001, December.*

*For further information, contact the Adaptive Systems Branch, NCCOSC RDT&E Division, San Diego, CA 92152–5001.

APPENDIX E: IMAGE CAPTURE AND PROCESSING

Dale Bryan

The tactical environment places some unique requirements on remote video surveillance and security system hardware. These systems have to be cost-effective due to their inevitable expendability in a combat zone. They have to be low power to operate over extended duration in areas where personnel may not be able to readily refurbish the systems. Communication of sensor data to remote operators has to be transmitted over noisy beyond line-of-site radio frequency (RF) channels using low bandwidth LPI/LPD military tactical radios. This requires smart image processing and robust, error-resilient, data-compression techniques to minimize data transmission time and receive the date error-free.

REQUIREMENTS

Image processing plays a major role in the AMGSSS program. There are potentially four vision sensors in the sensor suite for the AMP including a FLIR, daylight video camera, and up to two landing video cameras. The image processor onboard the AMP performs various image-processing tasks during an AMGSSS mission. In a typical mission, the image processor is used to determine a landing spot for the AMP at the surveillance location, provide visual feedback during autoland, perform video surveillance of the target area, enhance image regions of interest (ROIs), and compress imagery data for transmission over noisy low-bandwidth tactical military radio links. The following image-processing requirements were derived for the AMGSSS Program during 1993 (reference E-1).

Remote Landing Imagery

In the AMGSSS mission scenario, the operator's first imagery requirement occurs during the remote landing of the AMP. The platform has autonomously transitioned from the CDC to a position over a site previously selected by the operator. Once the AMP reaches the coordinates of that site, the operator must select a *good* spot to autoland the platform. Landing spot selection will require the operator to visually evaluate the area under the hovering AMP to ensure that it is free from obstacles, the vegetation is not too high, and the terrain slope is not too great. After the operator designates a landing spot, the AMP will be commanded to autoland. During autoland, the AMP will continually transmit landing-spot imagery to the operator. The operator inspects the images to verify the landing spot is clear.

Image-processing requirements include variable control of image size, resolution, and compression ratio for landing-spot selection, and video/image compression with variable control over frame rate (e.g., 1 frame/sec) during autolanding. A high bandwidth line-of-site communications link may be used during landing-site selection if channel conditions are suitable. This would allow real-time video or minimally compressed video to be transmitted directly to the CDC.

Landing Area Slope Determination

The AMP has a requirement to be able to land on terrain with a slope up to 30 degrees. During the landing phase of a mission, the AMP will be required to determine the slope of a selected landing area. Different scenarios are being evaluated for this task, including mounting two downward-looking cameras on the AMP, using a single downward-looking camera with inertial positioning to get different views of the same landing area, and using the daylight surveillance camera on a pan/tilt unit that can tilt down 90 degrees to look at the ground.

The image processor will be required to register images from two cameras or register different images from a single camera to perform stereo vision processing and develop a depth map for slope determination of the ground below the hovering AMP. This function could also be done at the CDC if the communications link data rate between the CDC and the AMP were sufficiently high.

Surveillance Image Processing

Once the AMP has landed, the AMGSSS mission scenario moves into a surveillance phase. At the beginning of the surveillance phase, a panoramic scene map of the surrounding terrain is compressed and transmitted frame by frame over the tactical radio link to the CDC. This scene map is constructed from a number of image frames segmented together to form a wide-area surveillance scene in both azimuth and elevation. The operator uses this panoramic scene map to pick areas of interest to conduct autonomous video and acoustic surveillance by the AMP during its mission. Image-processing functions during the surveillance phase include ROI selection, image enhancement, video motion detection, and image/video compression.

Image Preprocessing. The image processor will be required to do a number of preprocessing tasks depending on the changing scene conditions during the surveillance phase of a mission. These functions include electronic image stabilization to compensate for induced global frame jitter from wind, image contrast enhancement for those times during the day when the image scene has low signal-to-noise ratio, image edge enhancement for aiding operator location of man-made targets in the scene, sensor fusion for image enhancement, and filtering for image noise reduction.

Regions of Interest Imagery. Multiple ROIs are required during a surveillance phase to optimize video motion detection on the AMP, and minimize image transmission time to the CDC. ROIs are constructed of arbitrary width and height within an image frame or multiple frames. The ROIs represent high-interest areas (e.g., roads) as well as exclusion areas for video motion detection. ROIs are used in image transmission to send high-resolution subimages at faster update rates to the CDC over low bandwidth tactical radio links. These ROIs are pasted into the operator's panoramic scene map. When used in conjunction with video motion detection, a high-resolution ROI containing a moving target of interest can be transmitted to the CDC continuously in real-time and pasted into the static scene map to provide a real-time display of moving targets.

Video Motion Detection. Video motion detection along with acoustic detection are used by the AMP as cueing mechanisms for the operator. Video motion detection is performed on the AMP without any interaction with the operator, except for initial parameter setup. Initial parameter setup includes which image segments and ROIs within a surveillance panorama will be used for video motion detection. Thresholds, dwell time, time on target, and sensor are assigned for each given region. This information is sent to the AMP as a program that will be executed autonomously once commanded by the operator. When motion is detected, the image processor alerts the operator with the programmed response, either an image of the target, video stream, laser range to target, or audible tone. The AMGSSS program has a requirement of detecting personnel motion at a range up to 1 km and vehicle motion at a range up to 2 km. A further requirement of the video motion detector is to discriminate between random environmental motion and directed target motion, thereby reducing false alarm rates.

Image/Video Compression. The most important function for the image processor is image/video compression of video surveillance imagery for transmission over low-bandwidth, noisy tactical radio

links. A greyscale still image of size 512 by 480 at 8 bits represents approximately 2 million bits of data. The AMGSSS program has targeted a 16-kbps tactical RF data link between AMP and CDC. The radios of choice are the Army's Single Channel Ground-Air Radios (SINCGARS), which although operating at a digital data rate of 16 kbps, effectively pass data at more like 4 kbps. Without image compression, it would take 8.3 minutes to transmit the above image across a realistic SINCGARS link. Using a standard still-image compression scheme such as JPEG or NITFS 2.0, this same image can be lossy compressed at ~15:1 without perceptible degradation and transmitted over this same link in 33 seconds. Improvements of 3 to 5 times more compression are achievable for more advanced still-image compression algorithms like wavelets for the same perceivable image quality. Further improvements can be achieved if video-compression algorithms like H.263M or MPEG IV are used.

The image processor is required to compress still images at various sizes and resolutions in such a way as to maintain error resiliency and robustness when transmitted over a noisy RF radio channel. Compression ratio is selectable by the operator. Further, robust video compression algorithms are required for sending near real-time video streams of regions of interest at better than 1 frame/sec.

Low Weight

The AMP has a payload weight restricted to < 60 lb. This weight includes batteries needed to provide power for the sensor payload. The image processor must be developed using highly integrated processors, DSPs, and ASICs to keep its weight down without sacrificing performance. A target weight for the image processor is <10 lb.

Low Power Consumption

Power translates to weight on the AMP. The image processor must take advantage of highly integrated low-power programmable vision processor, DSP, and ASIC technologies to provide the functional image-processing requirements of the AMGSSS program and yet maintain low power consumption at the same time. Power consumption for the image processor is targeted at <10 W.

Low Cost

The AMP has a targeted cost of <$100K. Ideally, the AMP is cheap enough since its expendability during a mission is a consideration. At this cost level, the image processor must be <$10K to $15K to be cost effective for the AMP.

OPTIONS CONSIDERED FOR AMGSSS

Investigations into leading image/video compression and video motion detection approaches were conducted through database searches, attending relevant conferences, and direct contact/demonstrations of institutions involved in these areas of research and development. Most of this effort was performed during 1992–94 (reference 1). Approaches that showed similarity to AMGSSS program image-processing requirements were highlighted in this study. A major point from this investigation was that there were no institutions/vendors developing systems that met all of AMGSSS's image-processing requirements. There was only one system that even integrated video motion detection with image compression. This system was developed by Army Research Lab/Oak Ridge National Lab for the UGV Demo I program. This system was power consuming and bulky since there were no restrictions on weight and power for that program. Image processing for AMGSSS has to be a

highly integrated solution combining image/video compression, video motion detection, and image-processing functions because of restrictions on power, weight, and cost.

Still Image Compression Technology

One of the AMGSSS image processor's main tasks is two-dimensional spatial compression of a captured image frame. This enables surveillance and security imagery to be transmitted across a low-bandwidth tactical data link in reasonable times. Efficient coding techniques for imagery has been the subject of research and development for many years. The three most popular techniques for spatial compression are the discrete cosine transform (JPEG), fractal, and wavelet-based algorithms.

JPEG. The JPEG algorithm is based on the discrete cosine transform (DCT). This algorithm codes an image frame 8 by 8 pixel blocks at a time. The algorithm was developed in the 1970s and matured through the 1980s when it was developed into standards: JPEG for the commercial world and NITFS 2.0 for the DoD world. It is a symmetric algorithm, which means the encoder and decoder have essentially the same complexity. The algorithm has good subjective compression performance for image-compression ratios <30 to 40:1, but degrades rapidly at higher compression ratios. Degradation is in the form of blocky artifacts due to the nature of its block transform algorithm. It has the advantage of standardization, which enables it to be transportable over many systems, both commercial and military. There are a lot of products, both software and hardware, that use JPEG.

Fractal. Fractal compression is based on algorithms that exploit self-similarity within an image. This algorithm, like JPEG, breaks an image up into contiguous blocks, but unlike JPEG, these blocks can vary in size and shape. Fractal algorithms have been developing since the mid 1980s and have not yet matured. The algorithm is highly asymmetric whereby the encoder is much more complex than the decoder. This is due to the process of analyzing the input image to determine the different self-similar basis blocks. However, fractal decompression is fast. Fractal compression has good subjective performance for compression ratios <60 to 80:1, but compares quantitatively about the same with adaptive DCT (reference 2). Degradation is in the form of blockiness and geometric distortions. The fractal approach offers no advantage to AMGSSS due to its slow compression performance. Similar findings about the fractal algorithm have been seen at the Army Research Lab. There are a few companies making software and hardware products based on the fractal algorithm. These include Fed-Comm and Iterated Systems, Inc. (ISI). Fed-Comm uses ISI's fractal encoder chip on its PC-based product.

Wavelet. The wavelet algorithm is part of a larger class of multiresolution algorithms including subband coding and pyramid coding. These algorithms are transform-based like the DCT, but operate over the entire image instead of block by block. The wavelet algorithm has been developing since the mid 1980s and has not yet matured. The algorithm is symmetric and computationally faster than the DCT. This algorithm shows good subjective compression performance for compression ratios <100 to 150:1. Degradation is in the form of defocused areas and *mosquito* noise within the image. The wavelet algorithm looks like the best compression technology to date for the AMGSSS program. The wavelet algorithm offers a 3 to 5 improvement in compression performance over JPEG for the same-subjective image quality. It is a faster and less complex algorithm to implement than JPEG. Progressive-resolution image transmission is built into the algorithm, which is an important feature

for low-bandwidth data links. A disadvantage of the wavelet algorithm is that it is not part of a standard at this time. Similar studies of compression technology have been done for the military showing wavelets to be the best choice to date for applications similar to that of the AMGSSS program (reference 3). Companies have begun selling software- and hardware-based wavelet products. These companies include, Summus, Mac A. Cody Associates, Aware/Analog Devices, Fastman, HDS, and Magnovox/Hughes.

Video Compression Technology

Video compression technology incorporates an additional temporal dimension for compression in conjunction with the two-dimensional spatial approaches mentioned above. This provides much greater compression ratios for image data than spatial compression alone. Much of the information within an image frame and between successive frames in a video sequence is redundant. In video compression, *intraframe* redundancy is reduced using spatial-compression techniques, while *interframe* redundancy between frames is reduced using temporal-compression techniques. Table E-1 lists the current commercial video compression standards.

Table E-1. Commercial video compression standards.

Standard	Data Rate	Application
H.263(H.324)	<28.8 kbps	Videophone on PTSN
H.261(H.320)	56 kbps to 1936 kbps	ISDN video teleconferencing
MPEG I	1.5 Mbps	CD-ROM applications
MPEG II	4 Mbps to 20 Mbps	Broadcast TV, HDTV, DBS

All of these algorithms are based on DCT compression for intraframe coding and some predictive coding scheme with optional motion estimation/compensation for the interframe coding strategy. Some upcoming standards in the video compression area for low-bit-rate wireless data links are the extension of H.263 to H.263M by making it more error resilient to the noisier wireless channels; and, the development of MPEG IV, currently scheduled for 1998 standardization. MPEG IV has remote video surveillance called out as one of its application areas and it is also concerned with algorithm robustness in the presence of a noisy channel. An error resilient technique that is competing for inclusion in the MPEG IV standardization process was shown to be quite effective in side by side comparisons against baseline H.263 for a simulated channel having a random bit-error rate of 0.001 and burst errors of 16 msec and 24 msec (reference 5). Besides the video compression standards mentioned above, there exist proprietary schemes implemented by various companies. The AMGSSS program either purchased, borrowed, or saw demonstrations of the following systems during its evaluation of candidate video compression technologies.

IIT's DVC3. Integrated Information Technology has developed a programmable vision processor IC, the VCP, that contains seven function-specific processors on a single chip. The VCP consumes 2 watts of power. IIT sells the chip to OEMs. An evaluation board is available for the PC ISA bus that demonstrates the VCP's capabilities in implementing H.320, H.261, H.263, MPEG I video compression/decompression, and MPEG II decompression. The VCP also comes with JPEG code for still-image compression. Data rates are programmable down to 4800 bps. Compressed video data

are passed across the PC ISA bus at the programmed data rate and either written to files or looped back to the VCP for real-time decompression and display. The VCP can perform video compression and decompression simultaneously in real time. The DVC3 board is configured to demonstrate video teleconferencing (voice, video, and data). Video compression parameters for the DVC3 demo board such as frame rate, compression ratio, intraframe coding refresh rate, and image size are adjustable in real time using a PC-hosted interface program over the PC ISA bus. Its programmable nature makes it suitable for developing and integrating new algorithms for still-image compression, video compression, image enhancement, and video motion detection.

ISI's Video Teleport System. Iterated Systems Inc. has developed a fractal video compression product that runs on a PC. This commercial product is a result of SBIR work under contract to the Army. ISI developed a fractal ASIC for implementing the complex fractal encoder, while the fractal decompressor is a software-only solution. The system allows control of image size, image scaling, and data rate. The Video Teleport transmits the compressed video stream out the PC's RS232 port. The compression PC consists of a frame-grabber board, fractal-encoder ASIC board, and Windows-based encoder/decoder software. There is no control over compression ratio; rather this was fixed by ISI, based on quality tests performed. ISI uses a proprietary method for temporal compression that incorporates fractal compression of difference frames. This system has not progressed much since 1993, which was about the time the Army stopped funding ISI in favor of wavelet-based compression approaches.

SNL ITS System. Sandia National Laboratory has developed the Image Transmission System (ITS) for the Department of Energy (DOE). This system uses commercial JPEG software for intraframe coding and a proprietary frame-differencing approach for interframe coding successive frames. The ITS uses a PC ISA bus image frame grabber with software running under MS-DOS. Compressed video data is transmitted out the PC's RS-232 port. The ITS has been demonstrated using telephone modems and a spread-sprectrum radio modem. The ITS was developed to supplement physical security systems currently in use at DOE facilities. The ITS is also available in a low-cost embedded configuration. Sandia has investigated improvements to the ITS including progressive image transmission, image postprocessing, and algorithm modifications for error-resilient image transmission.

DIS's Demo I System. Delta Information System developed a video compression system under contract to TACOM for the UGV program's DEMO I. DIS's video compression system uses DCT for its intraframe coding and frame differencing for its interframe coding. The operator has control over the data rate, frame rate, and resolution. The system is implemented in rack-mounted VME hardware weighing 50 lb and using 150 watts. Delta Information Systems delivered their system to TACOM in January 1993. This system has remained unfunded and unused since then.

Delta Information System introduced (Fall 1995) a new video compression product called the Vidicoder. The Vidicoder is a single 3-inch by 5-inch board containing IIT's VCP vision processor. The Vidicoder consumes 3.5 watts and uses the H.320/H.324 video teleconferencing compression standard. The Vidicoder compression algorithm can be modified since the VCP is programmable. The operator has control over frame rate, data rate, image size, and compression ratio. Data are output as a RS-422 serial bit stream. The Vidicoder costs $5.5K. This type of product offers great potential for addressing the image-processing requirements for the AMGSSS program, especially in terms of cost, power, and weight.

ARL/ORNL's Demo I System. The Army Research Lab/Oak Ridge National Lab video compression system was developed for the UGV program and demonstrated during DEMO I in 1992. The video compression algorithm uses pyramid intraframe coding with frame differencing for the interframe coding. This system had a fixed data rate of 64 kbps. It is implemented in rack-mounted VME hardware weighing 50 lb and using 150 watts. At last check, this system remained unfunded since its demonstration at DEMO I.

There were a few other video compression systems that were not yet available at the time of this investigation from companies including Fed-Comm, Magnavox, C-Cube, array Microsystems, and HDS. Products like the IIT's DVC3, C-Cube's CL4000, and DIS's Vidicoder provide a high-performance, flexible approach to implementing and upgrading video compression solutions for the AMGSSS program.

Video Motion Detection Technology

Video motion detection is performed by the image processor on the AMP. Autonomous video motion detection plays a key role for the AMGSSS program. It relieves the remote operator from continuously monitoring surveillance imagery during a mission, and greatly reduces the tactical communications requirements between the AMP and the CDC during the course of a mission, thereby maintaining low probability of detection (LPD).

DSRC's VFE-100. David Sarnoff Research Center developed the Vision Front End (VFE) through contracts with the U.S. Army Missile Command (MICOM). The VFE-100 performs video motion detection and tracking. It also is capable of image-processing tasks, including image stabilization from a moving platform, sensor fusion (FLIR/TV), subpixel resolution techniques, and target recognition. The VFE-100 is based on multiresolution techniques (pyramid) for image decomposition and image processing. The VFE-100 hardware consists of rack-mounted VME cards weighing 20 lb and consuming 150 watts. DSRC formed a subsidiary, Sensar, to market the VFE-100 commercially. The VFE-100 was part of the UGV program's DEMO II demonstration. At the core of the VFE-100 is the PYR I chip. Several of these ASICs performs the pyramidal image decomposition and processing on the input video signal in real time. This chip could also be used for wavelet image-compression techniques. The MDARS program contracted DSRC in 1994 to develop a downsized version of the VFE-100 for target motion detection from a moving platform. DSRC also submitted a proposal to AMGSSS in 1994 to develop an integrated image processor based on a downsized VFE-100. This system would perform all of the AMGSSS image-processing tasks, compression, motion detection, slope determination, and image preprocessing, on a single 6U VME card consuming 30 watts. The proposal was based on the development of second-generation versions of the PYR I ASIC. The AMGSSS program was not in a position to fund any subsystem development at that time. DSRC finished a second-generation PYR II chip development in 1995.

ARL's ATA System. A group at the Army Research Laboratory, formerly from Harry Diamond Laboratories, has developed an Automatic Target Acquisition (ATA) system through funding from the UGV program. ARL teamed with ORNL for the UGV's DEMO I tests in 1992. ARL provided the video motion detection and tracking capabilities for the system while ORNL did the video compression tasks . The ATA was implemented in rack-mounted VME hardware. ARL also used DSRC's VFE-100 for image stabilization and registration tasks. This work was not continued by the UGV program after DEMO I.

NRL. Naval Research Laboratory (NRL) is developing VMD algorithms based on optical-flow methods. This work was established using IR funding. It has been proposed for vehicle detection and speed monitoring for IVHS and demonstrated for wide-area-surveillance applications. The algorithms are currently workstation-based.

SNL/NMSU. Sandia National Laboratory (SNL) is developing video motion detection algorithms for both daylight and FLIR sensors. This work is being funded by DOE and DNA for facilities' physical security applications. SNL has developed VMD algorithms that have been transitioned to embedded hardware. SNL has demonstrated VMD algorithms running on PC-based and STD32 bus architectures. SNL is teaming with New Mexico State University (NMSU), which is developing knowledge- based tracking algorithms to work in conjunction with SNL's VMD algorithms.

In addition to the ongoing VMD work at Sandia, there is a group, the Intrusion Detection Technology Department, tasked with evaluating commercial VMD products for DOE. This group reports on the performance of commercial VMD systems for detecting intruders in an exterior setting at ranges out to 250 feet from the camera (reference 5).

Low-Power, Lightweight, Cost-Effective Solutions

The optimum solution in terms of weight, power, cost, and performance for an AMGSSS image processor is a programmable vision processor in conjunction with the large market base of COTS-embeddable-hardware bus architectures (VME, STD32, PCI, ISA, PC/104). Programmable vision processors are highly integrated inexpensive chips/chipsets that perform a variety of image-processing tasks using multiple processors on a single chip while consuming only a couple of watts. Although the chips are inexpensive, the development tools for these chips can range in cost from \$20K to \$100K. These multiprocessor chips are categorized into two groups, heterogenous and homogenous processors (reference 6). Homogenous processors are multiple versions of the same processor on a single chip, while heterogenous processors are multiple processors on a chip (each processor is optimized for a specific function). A heterogenous vision processor is more capable if a given image-processing task and power requirement than a homogenous vision processor due to the function-specific nature of a heterogeneous vision processor. However, it is less flexible to program than a homogenous vision processor.

A vision processor(s) could be programmed to perform all of the AMGSSS image-processing tasks, including image compression, video compression, motion detection, slope determination, image enhancement, and image stabilization. Several vision processors were investigated for the AMGSSS program, including IIT's VCP chip, C-Cube's CL4000 chipset, array Micosystem's VideoFlow chipset, and Texas Instrument's TMS320C80 chip. An ISA bus demo board with IIT's VCP heterogenous vision processor chip was purchased and evaluated. At the time of this investigation, C-Cube, array Microsystems, and Texas Instruments products were not available yet. The VCP demo board came with programs that performed JPEG still-image compression, H.261 and H.320 video compression, image scaling, and image-resolution control. One of the seven onboard processors of the VCP is a block matching processor used in motion estimation for video compression algorithms. This processor could be programmed for video motion detection for AMGSSS. The IIT VCP development tools cost \$80K. When normalized for H.261 video compression performance, the VCP provided the best performance versus chip silicon area (power) for a variety of VLSI vision processor architectures (reference 6).

AMGSSS Image-Processing Evaluation Videotape

Video data were collected at Fort AP Hill in Virginia and Camp Pendleton in California. This video data included representative imagery for a wide range of AMGSSS mission scenarios. Lighting conditions included day, night, dusk, dawn, and backlit settings. Weather included sunny, cloudy, rainy, dusty, windy, and smoky conditions. Environmental conditions included meadows, woods, desert, and urban terrain. Both daylight and FLIR video was taken for all scenarios with moving targets including personnel, cars, trucks, HMMWVs, tanks, APCs, and helicopters. Target ranges were 0.5 to 2 km for personnel, and 0.5 to 5 km for vehicles. Video data were edited into a videotape that can be used to evaluate vendor systems performance for meeting AMGSSS image-processing requirements.

OPTIONS CONSIDERED FOR THE MPP IMAGE PROCESSOR

In 1995, the AMGSSS program changed direction due to funding restrictions. It was decided to develop a mission payload prototype (MPP) sensor subsystem with a corresponding laptop-based operator console (reference 7). The development concept was to put together low-cost COTS hardware and software that were available at the time within the power and weight constraints of the current AMP platform. Furthermore, it was decided to package the hardware in a suitcase-type form that would easily fit under a commercial airline seat.

Rapid prototyping was another driving factor in the MPP development due to midyear arrival of FY 95 funding. To facilitate rapid prototyping of the MPP hardware and software, several key design decisions were made:

- Leverage development off the large COTS-embedded PC-hardware market.
- Minimize software development time by using available COTS software libraries and drivers.
- Distribute MPP tasks into functional processing elements that are scalable.
- Facilitate MPP virtual system design by implementing TCP/IP for interprocessor communications and using the Internet during development and testing.

Driven by the above criteria, the options considered for MPP image processor (IP) were constrained to variations of readily available PC-based COTS hardware and software products. Alternatives for the IP fell into the three categories discussed below.

Option 1: X86 Hardware/Software

This option consists of ISA and PC/104 bus adapter boards controlled by a host X86 (386, 486, or Pentium) processor through DOS-based software tools. The X86 processor can reside on either a single board computer card, ISA adapter card, or a PC/104 card. Software tools include libraries and drivers that come with the various hardware adapter boards (e.g., frame grabber) and an X86 C compiler for custom code development. This approach was the lowest risk because of the large product base in both hardware and software solutions available for the PC market. It was also the most flexible approach because the existing IP hardware/software components can be easily upgraded as new and more capable PC-based hardware/software products (e.g., better compression library) become available. This option represents the lowest performance of the three due to the execution speed of the X86 microprocessor in performing image-processing tasks, and data transfer rates across the ISA bus. Option 1 costs range up to ~$5K.

Option 2: X86 + DSP Hardware/Software

This option consists of an X86 host processor working in conjunction with a DSP coprocessor ISA or PC/104 bus board. This option requires two software development environments. One for the X86 microprocessor and another for the DSP chip, each with its own compilers, debuggers, drivers, and libraries. This option is less flexible than Option 1 in the sense that there are less COTS products available for a given DSP chip than there are for PC-based X86 processors. Option 2 offers better performance over Option 1 because IP image-processing algorithms will run faster on a DSP, and if the DSP coprocessor board is properly designed, the ISA-bus data-transfer bottleneck can be eliminated. Option 2 costs were ~$15K.

Option 3: X86 + Vision Processor Hardware/Software

This option consists of a host X86 processor controlling a vision processor ISA bus adapter board. Like Option 2, this option requires two software development environments, one for the X86 host processor and one for the vision processor chip. Option 3 is the least flexible in terms of available third-party COTS software libraries to leverage image-processing task development. Any available application libraries will likely only be from the vision processor chip vendor. This option represents the highest risk for MPP development due to the time required to ramp up the learning curve on programming a specific vision processor chip. However, this option provides the highest performance solution for IP image-processing task development due to the functional multiprocessor design of a vision processor chip. Option 3 costs range from $47K to $100K.

At decision time in the design of the IP, only one vision processor product was available on the market, the IIT VCP. At that time, IIT was not willing to sell its software development tools for applications like ours where OEM quantities were not involved.

DEVELOPMENTS FOR THE MPP IMAGE PROCESSOR

The hardware bus architecture chosen for the MPP was the PC/104 format. This architecture features PC ISA bus compatibility, low cost, low power, and small form factor (3.5" by 3.5"). The PC/104 architecture is targeted for the industrial embedded computer market. The PC/104 vendors have taken advantage of the low-power, highly integrated technology developments driven by the PC notebook market. The MPP and operator console represent an extendable and distributable system (reference 8). Each processing element can be remoted by using tactical radios, wireless Ethernet modems, or the Internet. The IP is one of three independent PC/104 processing elements in the MPP. These processors transfer data between themselves and the operator's console using the TCP/IP protocol over an ethernet network connection.

What is the IP?

The IP consists of a 486 DX4 100-MHz ISA bus CPU board stacked with three PC/104 cards: a video framegrabber, Ethernet data interface, and solid-state disk (SSD). The IP consumes 12 watts. The IP is programmed in Microsoft C and uses MS-DOS based software application libraries for video framegrabbing, image compression, and TCP/IP network connectivity. A fast processor is needed for computer-intensive, image-processing tasks. During hardware selection for the IP, the fastest PC/104 CPU board was a 50-MHz 486. This was not deemed fast enough so an ISA bus 486 DX4 100-MHz single-board computer was selected. Today, this board along with the SSD PC/104 board, can be replaced with a single PC/104 CPU board without modification of the software. Pentium (3 V) PC/104 CPU boards are projected to be available in the fall of 1996. The current IP hard-

ware configuration could be replaced with a three-card PC/104 stack consuming <5 watts by the end of 1996. An important feature of the IP is its application as a testbed for low-power, highly integrated embedded image-processing solutions.

IP Image-Processing Functions

The IP performs the image-processing tasks of the MPP. These tasks include input source selection (FLIR/TV), noise filtering, image enhancement preprocessing, video motion detection, image compression, and video compression. These IP tasks are described below.

Input Source Selection. The IP selects between two video-input sensors, the FLIR and TV cameras. The IP is capable of selecting between six video input signals. The IP can accept a wide variety of video-input formats including PAL, NTSC, and CCIR 601. These video formats can be interlaced or noninterlaced. The IP low pass filters the selected input video and applies a noise-reducing, three-tap digital FIR filter.

Image-Enhancement Preprocessing. The IP performs operator-selectable, image-enhancement preprocessing functions including region of interest subimage selection, contrast enhancement, histogram equalization, and automatic FLIR level and gain control.

The automatic FLIR level and gain control is performed in conjunction with the payload processor.

Video Motion Detection. The IP has simple video-motion-detection algorithms. Successive image frames are recaptured and subtracted from each other. Pixel differences exceeding a deadband zone around zero are binary-thresholded. The binary-thresholded image frame is nonlinearly processed with a median filter to reduce noise and enhance target pixel clusters. The number of target pixels is compared against an operator-selectable threshold. If the threshold is exceeded for a programmable consecutive number of times, then a motion-detection alert is transmitted to the payload processor.

Image Compression. The IP uses an MS-DOS software compression library for still-image compression. The still-image compression algorithm used is JPEG. This algorithm is freely available from the Independent JPEG Group (IJG). The operator selects the compression ratio used by the IP during image compression. The latest version of IJG JPEG supports progressive transmission, which when implemented in the IP, will improve MPP system operational performance over tactical radios. Wavelet algorithms have been purchased but not implemented in the IP. These algorithms offer improved performance over JPEG algorithms in areas of compressed image quality, progressive transmission, and differential area enhancement.

Video Compression. A video compression algorithm has been developed and tested but not implemented for the IP. This was due to the slow data-transfer rate using tactical radios. The algorithm includes JPEG compression for intraframe coding. Interframe coding consists of frame differencing of decompressed frames against a decompressed reference frame. The difference frame is then decomposed into a 1-bit position map and an array of difference pixels. The position map is losslessly compressed using a Group 4 fax technique while the pixel array is losslessly compressed using an LZW technique.

A video compression algorithm has recently been acquired for the IP from the International Telecommunication Union (ITU) Study Group 15's (SG 15) open software web site. The ITU SG 15 committee is developing the next-generation video-compression standards for the PTSN and the

wireless cellular markets. This algorithm is known as H.263M and is an enhancement of H.261 used in video teleconferencing. H.263M has some error-resilient features built into the algorithm to combat the noisy channels found in the mobile cellular world. This algorithm is slated for final standardization in late 1996.

IP Data Transfer

An important feature of the IP, as well as the other processors in the MPP, is the use of the TCP/IP protocol and Ethernet network connectivity as its data communications mechanism between processing elements. Each processor uses a state machine to determine who it is connected to on the network and how to process its data accordingly. For example, if the tactical radio ethernet processors are replaced by the Internet as the communications link between MPP and operator console, the IP will sense this and transfer its data directly to the operator's console computer. Depending on connected processing elements, the IP can work directly with the operator console computer or through the payload and radio processors.

IP Issues

During MPP field tests, it was determined the the IP video framegrabber did not work properly with the Inframetric's Infracam FLIR camera. This was due to the noninterlace NTSC format of the FLIR's video output signal and the inability of the IP framegrabber to handle this signal correctly. A new framegrabber with software library was purchased that could handle the noninterlace video format. This new framegrabber and software were integrated into the IP in less than a month.

Video-compression algorithms have been tested but not implemented in the IP hardware. The tactical radio link operates too slowly for video compression to work effectively. The radio protocol at present is not appropriate for video data streaming. Long delays were observed in data transfers due to ACK/NACKs that would greatly inhibit temporal redundancy reduction algorithms used in video compression. A different radio protocol is needed for video compression to work effectively over tactical radios.

A PC/104 framegrabber board with DSP was purchased for the IP with the hopes of improving IP image-processing performance. This product came with JPEG compression software written for the DSP; however, this algorithm ran slower than the 486-hosted JPEG algorithm we were currently using. The main reason for this was due to limited memory available for processing on the PC/104 board and part of the JPEG algorithm being hosted on the PC host processor board. It is hoped that future products of this kind will fix these problems, thereby providing an improvement in IP image-processing performance.

CONCLUSIONS

The AMGSSS image-processing tasks have to be combined into an integrated image-processing subsystem. This is the only approach that will satisfy the very restrictive requirements for power, weight, and cost without sacrificing subsystem performance. An integrated image-processing subsystem is one that incorporates compression, video motion detection, terrain slope determination, and various image-enhancement features. Any image-processing hardware solution should take advantage of recent developments in low-power, programmable, multiprocessor vision ASICs.

Image-preprocessing tasks should not be underestimated for tactical surveillance applications such as AMGSSS. These tasks play a vital role in providing the essential surveillance imagery data to the

operator over low-bandwidth LPI/LPD tactical radio links. Important tasks include global image stabilization of video sensor jitter induced by wind, image contrast enhancement during times of the day when surveillance imagery has low signal to noise, linear and nonlinear image noise filtering techniques, edge enhancement for aiding operator detection on manmade targets, and sensor fusion to increase target signal-to-noise ratios.

A videotape was developed for the AMGSSS program. This videotape is used to evaluate vendor image-processing hardware and software in performing AMGSSS video surveillance tasks in all types of weather and environmental conditions over the course of a 24-hour day.

During MPP field tests with SINCGARS and PRC-139 VHF tactical radios, it was determined that existing military data-transfer protocols were not appropriate for video streaming data. Protocols need to be established for video data streams that reduce the transmission delays between radio packets that currently occur because of data packet ACK/NACKs that ensure error-free transmission. Error-free transmission techniques produce latency effects that reduce temporal redundancy, thereby reducing video-compression efficiency. Error-free transmission is not required for video streaming since data are continually being updated.

The MPP IP is an example of a low-cost, low-power embedded image-processing subsystem for surveillance applications. It consists of COTS PC/104 hardware and MS-DOS application software making it easily upgradeable as better commercial products become available. Examples of this include faster lower power CPU boards, more functionally integrated PC/104 boards, and better image-compression application software packages.

The IP uses the TCP/IP protocol for its interprocessor communication scheme. This method of interprocessor communications provides an easily scalable functional architecture. The IP is an independent processing element that can function in stand alone fashion with an operator control computer, or in conjunction with other processing elements such as in the MPP.

As an embeddable image-processing testbed, the IP is used to investigate and develop robust algorithms for remote video surveillance applications. These algorithms include: error-resilient image/video compression techniques for transmission over noisy radio channels; image enhancement and redundancy reducing preprocessing techniques; and, robust video motion detection techniques for noisy surveillance scenes. Currently, the IP software is being sent to Sandia National Laboratory where video motion detection algorithms can be integrated. Because of the distributive feature of the MPP system design, the SNL algorithms can be tested in the MPP subsystem over the Internet with the IP existing in Albuquerque, New Mexico, and the rest of the MPP in San Diego, California.

RECOMMENDATIONS

These recommendations fall into two categories: those for the MPP IP and those for the AMGSSS IP. In general, the AMGSSS IP recommendations include those of the MPP IP.

MPP IP

- Develop a new tactical radio data transfer protocol conducive to video streaming.
- Implement H.263M video-compression algorithms.
- Implement wavelet still-image compression algorithms.

- Provide operator-selectable choice of still-image compression algorithm between JPEG, progressive JPEG, NITFS 2.0, wavelets, and progressive wavelets. This will provide interoperability when needed and performance when not.
- Develop error-resilient image/video compression techniques.
- Develop image-stabilization algorithms.
- Investigate FLIR/TV sensor fusion algorithms.
- Develop improved robust video motion detection algorithms. This could be facilitated through teaming with Sandia National Laboratories and New Mexico State University.
- Upgrade PC/104 hardware to low-power Pentium (3-V) CPU card and more advanced DSP framegrabber. This will reduce MPP IP size and power while increasing image-processing performance.
- Purchase vision processor chip and software development tools. Implement image-processing algorithms on vision processor chip.
- Develop PC/104 board with vision processor chip. This could be accomplished by having Delta Information Systems downsize its Vidicoder (3" x 5") product.

AMGSSS IP

- Fund two different approaches for developing an integrated image processor for AMGSSS that conforms to the power, weight, and costs constraints. A downsized version of David Sarnoff Research Center's VFE-100 represents a good choice for one approach. The Delta Information System's Vidicoder vision processor board represents another good approach for AMGSSS.
- Purchase the VFE-100 and its software development tools for AMGSSS image-processing tasks development.
- Generate a Broad Area Announcement (BAA) for soliciting proposals to develop slope determination algorithms for AMGSSS.

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APPENDIX F: ONBOARD CONTROLLER

Doug Gage

Control processing tasks onboard the MPP Remote Platform are divided between three processors: the Image Processor (IP), Radio Computer (RC), and the Payload Processor (PP), which intercommunicate via Ethernet LAN and TCP/IP protocol. This partition of functionality is motivated by the fact that both the IP and RC make heavy use of software packages written by other agencies/companies, and this physical partitioning reduces the possibility of interference between "black box" software modules, as well as facilitating the simultaneous development of the separate processing subsystems. The IP and RC are discussed at length in appendices E and C respectively; this appendix focuses on the PP software.

REQUIREMENTS/ BASELINE DECISIONS

The PP provides the remote user, through the CDC, with the ability to control the sensor resources onboard the RP: TV camera, FLIR camera, laser rangefinder, Azimuth-Elevation (Az-El) mount, and acoustic sensing system. It does this by accepting and executing user commands from the CDC, returning system and subsystem status messages to the CDC, and coordinating the acquisition and flow of image data from the IP back to the CDC. Command execution requires communication with the sensor subsystems via RS-232 serial streams (FLIR, laser rangefinder, pan/tilt, acoustic subsystem) and/or discrete signals (TV focus and zoom) via a relay board.

The PP, like the IP and RC, is implemented on PC-104 form-factor processing boards using the MS-DOS operating system, reflecting (1) the need for high-performance, compact, and low-power processing hardware capable of hosting the driver software provided by the Az-El vendor and (2) the availability of compatible I/O hardware (RS-232 ports, relays, Ethernet) required to interface to the sensor hardware and the other subsystems.

The PP software is written in the C language, for compatibility with the Az-El driver software, to facilitate the reuse of other software modules—such as the serial and TCP/IP Service packages, and the Command Line Interpreter—previously written for the MIUW-SU and other NRaD software development efforts, and to effectively leverage project programmer skills, experience, and the installed base of development tools.

OPTIONS CONSIDERED

An alternate architecture that was considered was the implementation of the onboard controller as a network of LONWorks (reference F-1) nodes. LONworks is an architecture, developed by Echelon Corporation, for distributed control networks ("Local Operating Networks") of compact inexpensive controller nodes, applicable to building automation or to the integration of complex systems such as automobiles. Each LONWorks node incorporates an inexpensive microcontroller (manufactured by both Motorola and Toshiba) called a "Neuron" chip, which is capable of handling many control applications itself, and which can also be used as a "front end" communications processor for subsystems requiring more processing horsepower than the Neuron can provide. LONWorks provides a fully developed seven-layer protocol stack in which subsystem control, status, and data parameters are represented as "network variables," and the communication of network variables between nodes is completely transparent to the system implementer. Unfortunately, the development of a LONWorks system requires the purchase of proprietary development tools from Echelon at a price that was, until early 1995, in excess of $25K, so this option was not pursued. Nevertheless, an internal

interface layer was included in the PP implementation in which sensor subsystem parameters are represented by data structures analogous to network variables, in order to facilitate a future incremental introduction of LONWorks or similar technology into the AMGSSS system.

REMOTE PLATFORM FUNCTIONALITY

One key to the successful implementation of a complex remotely controlled system is the establishment of a clean model—precise yet intuitive—in the minds of both system users and implementers for the functionality to be provided to the operator's station by the system's remote element. The protocol between remote vehicle and operator station is essentially that between a server and a client. In the case of the AMGSSS MPP, RP functionality is defined in terms of a well-defined set of commands, which the PP is prepared to accept and execute.

High-Level (View) Commands

The MPP operator at the CDC sees RP functionality principally in terms of images being displayed at the CDC after they have been acquired and transmitted by the RP. The CDC passes an image specification (or *view*) to the RP, and the RP acquires and returns the image as soon as it can. A view specifies: the direction the Az-El mount is to point, whether the TV or the FLIR camera is to be used, how the camera is to be configured (focus and zoom values for TV; image polarity, level and gain for FLIR), and how the acquired image is to be processed by the IP (cropping, image compression ratio).

Alert Response Specification

The MPP has two capabilities for explicitly detecting potential threats. The acoustic detection subsystem sends the PP a report of acoustic detections every 1.25 seconds, each acoustic source being labeled with its azimuth from the MPP; its type (ground vehicle, propeller aircraft, jet, aircraft. helicopter; or unknown); and a measure of the acoustic subsystem's confidence in the detection. The CDC operator can install filters in the PP to specify which acoustic detections will be forwarded to the CDC, and also specify whether to automatically return an image and/or a laser range. The IP's motion detection function is invoked with a view command, and the operator can also specify whether to automatically return an image and/or a laser range when motion is detected.

Low-Level Commands

An extensive set of low-level commands allows the user more detailed control of the RP's subsystems, e.g., set the Az-El azimuth to -30 degrees, set the TV zoom to 20, increase the FLIR gain by 35. These commands are intended to support system integration and debugging, and troubleshooting in the field.

Command Programs

Both high-level and low-level commands can be strung together in command programs up to hundreds of steps long. Programs are usually used to acquire a panorama of images, or to repeatedly (via the special command REPEAT) scan a number of potential threat directions with motion detection. Programs are downloaded from the CDC and can also be uploaded back to the CDC for inspection and validation. The PP can store three programs, but only one program can be executing at any one time; the operator controls program execution with the PP commands RUN, HALT, and CONTINUE.

PP SOFTWARE IMPLEMENTATION

Command Execution Process

Many RP subsystem functions take a very long time when measured in terms of processor execution cycles. For example, a full pan excursion of the Az-El takes almost 2 seconds; a full range camera lens zoom excursion takes 6 seconds; and the FLIR takes several minutes to initially cool to its operating temperature. Hence the PP software must be written so that long-duration commands do not tie up the PP's CPU, which is running plain old single-threaded DOS as its "operating system." Moreover, operations of different subsystems must be allowed to overlap, so that the Az-El can be panning while the camera lens is zooming and so forth. On the other hand, high-level view commands require that subsystem operations be properly sequenced to succeed. For example, in response to a view command, the PP must be able to command the Az-El to its new position and then immediately command the camera zoom and focus to their new values. When both operations have completed, the PP must wait an additional 2 seconds for the camera auto-iris to stabilize, and only then command the image processor to grab and process the image.

To support this flexibility of operation, a resource lock mechanism has been implemented that permits the simultaneous execution of multiple commands not requiring the same resources, while forcing commands that require resources already in use to wait until those resources become free. Resource granularity is at the subsystem level, i.e., pan/tilt, TV, FLIR, laser rangefinder, and image processor.

The command execution process involves two levels of procedure calls, each involving a state machine. When the resources required for a command's execution become available, the ExecCmd procedure is called with the command's op-code and parameters (e.g., view data structure), and initial state (cmd->state) equal to 1. ExecCmd, after marking the resources it is using as busy, generally invokes a subsystem-specific process, communicating the required actions via variables analogous to LONWorks network variables. For example, if the camera zoom is to be increased by 20, then ExecCmd sets the desired zoom value (vis.newZoom) to 20 plus the current zoom value (visS->zoom), then sets the state variable (vis.state) for the camera specific process (VisProc) to 1, gives VisProc a pointer to this command (vis.cmd), sets its own cmd->state to 2, and returns.

VisProc is called on every pass through the main program loop, but returns immediately if vis.state equals 0 or 9. When vis.state is 1, however, VisProc sets a timer that closes the zoom-in or zoom-out relay for the required time, sets vis.state equal 2, then returns. When VisProc is called with vis.state = 2, it returns immediately if the zoom timer is non-zero (i.e., if the relay is still closed); when the timer has finally timed out, VisProc sets visS->zoom equal to vis.newZoom, sets vis.state to 0, and calls ExecCmd again.

ExecCmd now sees that cmd->state = 2, and, if this is a simple command to change zoom, it proceeds to clean up by setting vis.state = 0, marking its resources as not busy, and setting cmd->state = 0; then it returns. On the other hand, if this is part of a more complex command involving an image capture, then ExecCmd can delay the VisProc cleanup in order to prevent another command from changing the camera settings before the IP has captured the image.

Separate procedures are called each program loop for the Az-El, FLIR, camera (vis), laser rangefinder, and image processor resources.

Coordination of Image Transfer with Image Processor and Radio Computer

An extension of this simple state machine concept to multiple processors provides flow control for the transfer of (potentially) large image files from the IP to the RC, and thence via the radio channel to the CD. The IP is one of the resources used by PP commands, and a PP process ImageProc is called much like VisProc as described above. The PP sends a command message to the IP to acquire an image, and marks the IP as busy until the IP acknowledges that it is ready to take another image. The IP, however, does not send this acknowledgment until it has successfully transferred the image to the RC and received a reply confirming that the RC is ready to accept another image file. Hence, when the PP is executing a program to take a sequence of images (e.g., a panorama), images are taken in rapid succession until the RC's buffers can no longer accommodate another maximum-sized image, whereupon the RC delays its acknowledgment to the IP until enough buffer space has been freed by successfully acknowledged transmission over the radio channel to the CD.

Command Sources

The main loop of the PP software attempts to execute commands from a number of different sources, in round-robin sequence:

- If a message containing a command has been received from the CD or one of the other sources discussed below, then, if all resources required to execute the command are available, the command is executed; if any required resource is busy, then the command is placed on the tail of the command queue.
- If the command queue is not empty and if all resources required to execute the command at the head of the queue are available, that command is removed from the queue and is executed; otherwise the queue is left unchanged. This scheme ensures that commands in the queue are executed in the order in which they were queued, but also means that a command waiting for a busy resource can block the execution of other commands whose required resources are available.
- If a command program is running (active) and if all resources required to execute the next command step of the active program are available, that command is executed and the program pointer is incremented to point to the next step; otherwise no action is taken. If the next command is a NOOP, the pointer is incremented again; if it is REPEAT, the pointer is reset to the first step of the program.

This command flow is depicted in figure F-1.

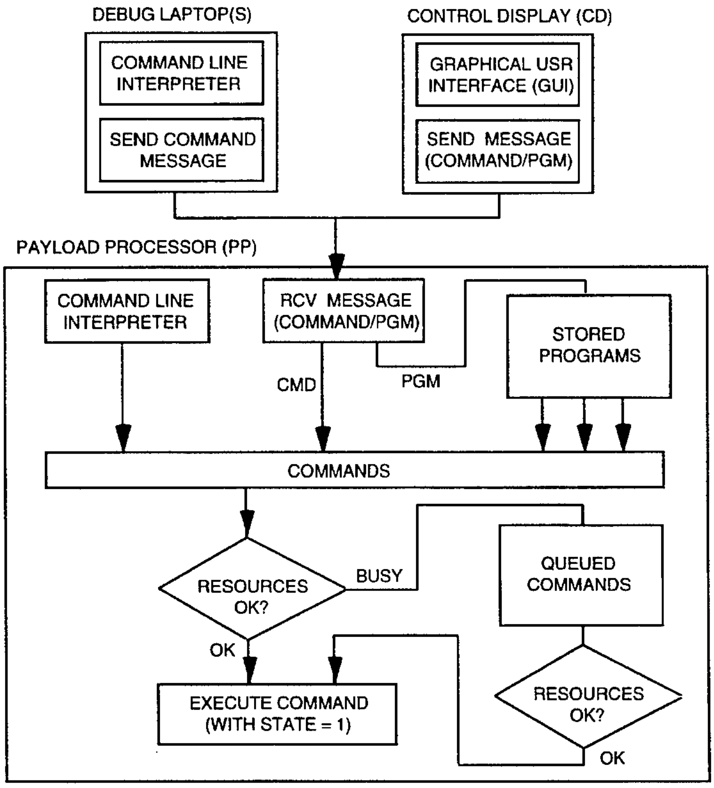

Figure F-1. Command flow.

Command Line Interpreter (CLI)

To support system troubleshooting and maintenance in the field as well as debugging during system development and integration, the PP incorporates a Command Line Interpreter (CLI) to allow a user to quickly and concisely interact with the PP at the subsystem level. This CLI software has been evolved over about 15 years, and has been used in many projects implemented on computer platforms ranging from the Commodore PET and simple 8-bit microcontrollers to the PC, Macintosh, and Sun Workstation. The CLI has the following features.

For ease of remembering, commands are sequences of words, plus optional parameters. The syntax chosen for the PP is <subsystem name> <parameter name> <action> (omission of <action> implies "show current value"). So the following are valid PP commands:

VIS Zoom <cr>	(show current value of camera's zoom variable)
VIS Zoom = 33 <cr>	(set camera zoom value to 33)
VIS Zoom +	(increment camera zoom by VIS Zoom Delta)
VIS Zoom Delta <cr>	(show current value of camera zoom increment variable)
VIS Zoom Delta = 8<cr>	(set camera zoom increment variable to 8)
FLIR Gain = 320<cr>	(set FLIR gain variable to 320)
Pan/Tilt Center<cr>	(command Az-El mount to move to 0,0 home position)
Laser Units Meters<cr>	(command rangefinder to return values in meters, vice yards)
Software Queue Display	(show list of queued commands)

For ease of command entry, the user types only the first character of a command word, and the CLI echoes the entire command word. Actually, the programmer can choose almost any character to trigger a given command, so in fact the user types “SXK<cr>” to enter the command:

Software eXecuting-Commands Kill<cr> (kills all commands currently executing)

Typing <del> while entering a command erases the last command word (or the last character of a parameter string being entered).

Typing “>” while entering a command “remembers” the command words already entered, so that, for example, the user can easily focus on one subsystem, and this mode is reflected in the CLI prompt, which displays the remembered words before the prompt “>”. If, for example, the user wanted to repeatedly increment the FLIR gain while looking at an attached monitor, he could enter “FG>” and then would have to type only “+” instead of “FG+” each time. Typing “<” erases the last remembered word, moving the prompt to the left.

The user can type ? while entering a command to see the command options currently available. For example, if the user types “FD?” the screen displays:

```
>FLIR Display-polarity
        White-hot
        Black-hot
>FLIR Display-polarity
```

The command Help<cr> toggles the CLI between this basic level of prompting and a second, more complete level. After executing Help<cr>, the same entry of “FD?” yields:

```
>FLIR Display-polarity
        White-hot                      use White to indicate hot
        Black-hot                      use Black to indicate hot
>FLIR Display-polarity
```

The CLI command set itself is defined by a single data structure, so implementing the command set for a new application requires changes only to the data, not the C code. The data structure specifies the command set structure (what command words are active at any point in the entry process), and, for each command, the character that must be typed, the command word for display, and the “help enabled” prompt string.

The CLI is written in ANSI C and uses only standard console I/O, to make it extremely portable.

In addition to the CLI hosted on the PP itself, CLIs on other laptop computers can interact with the PP via messages exchanged over the Ethernet or a serial port (in the current implementation, a debug computer can be connected to the PP via the serial port that normally handles the acoustic detection system). Multiple CLIs can interact with the PP simultaneously, so that, for example, one operator can troubleshoot the FLIR while a second operator reconfigures the laser rangefinder. While the human operators must currently explicitly coordinate their activities to avoid interfering with each other, a “session layer” protocol based on the resource lock mechanisms described above could easily be implemented to prevent such interference but allow control of individual subsystem resources to be passed between multiple users. This same session layer mechanism will also support the

orderly transfer of control of the entire remote vehicle from one control station to another, should that be desired.

Log Messages

A PP procedure named Log (not to be confused with the C function *log*, which computes the natural logarithm) is provided to allow the PP software coder to sprinkle the code liberally with debug statements written using familiar *printf* format conversion specifications, while at the same time allowing the PP user to decide on the fly which classes of Log messages to actually see and where to see them. Log messages are automatically timestamped, and can be written to a file to create a detailed timeline of system activity. The programmer associates one bit of the Log function's *flag* argument to each of a number of debug message categories:

1	subsystem procedure activity
2	command execution activity
4	non-status message traffic
8	buffer activity internal to the messaging process
16	status message traffic (usually not of interest in debugging)
32	acoustic subsystem detections and acoustic simulator
512	software error condition

A call to the Log function actually produces the Log message only if the bitwise AND of the *flag* argument and the PP global variable *logFlag* is nonzero; otherwise, it immediately returns. The CLI command Software Logflag = <value> <cr> allows the PP user to see any desired subset of the message categories.

CONCLUSIONS AND RECOMMENDATIONS

The AMGSSS MPP Remote Platform's onboard controller, with the Payload Processor (PP) as its core, implements a well-defined "server" functionality, executing commands it receives from the CD, and (especially for debugging purposes) from other clients, including the PP's own Command Line Interface (CLI). Mechanisms implemented on the PP support debugging as well as operational requirements, and have been designed to easily accommodate the integration of additional or enhanced sensor subsystem components.

Recommendations for future development of the onboard controller are:

Enhanced Robustness for Subsystem Control

The PP communicates via RS-232 links with microcontrollers embedded within several COTS subsystems: pan/tilt unit, FLIR, laser rangefinder, and acoustic detection system. These microcontrollers maintain internal state information that should be "mirrored" by the subsystem state information held by the PP itself. Error conditions or other events of interest internal to the subsystems, however, may not be adequately reported to or detected by the PP. The PP should be enhanced to deal with these situations more robustly. Specifically,

- The low-level C code controlling the pan/tilt unit should be reviewed, cleaned up, and made much more "bullet proof," since what currently exists is basically a quick-and-dirty encapsulation of core procedures from TRC's pan/tilt demonstration program.
- Additional error checks should be inserted into the low-level code interfacing with the FLIR and laser rangefinder.
- Opportunities for the insertion of LONWorks technology into the onboard controller should be reassessed, since development tools are now available in-house.

Enhancement of Message Addressing

The message-addressing scheme used in AMGSSS should be refined to incorporate process ID within the platform or CD as well as platform ID. The TCP/IP "service" model now employed should be replaced by a UDP messaging scheme incorporating explicit source and destination addresses. This will support flexible operation and debugging activities in an environment including both multiple AMGSSS vehicles and multiple CDs.

It should be kept in mind, however, that the most critical current deficiencies in the AMGSSS MPP systems involve the tactical radio link and its controller, and not the onboard controller per se. Moreover, once the radio link's performance has been optimized, it is almost certain that the details of the CD's operator interface will become the focus of management attention. Nevertheless, the above recommendations related to the onboard controller should be pursued if the AMGSSS project is to proceed.

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APPENDIX G: CONTROL DISPLAY CENTER

Hoa Nguyen and Bill Marsh

OVERVIEW AND FUNCTIONAL REQUIREMENTS

Figure G-1 shows the AMGSSS Mission Payload Prototype (MPP) system functional diagram, showing connections between the subsystem computers. There are two computers at the control end (a laptop running the control display and optional payload simulator, and a tactical radio/Ethernet modem), and three computers on the remote payload side (payload processor, image processor, and tactical radio/Ethernet modem). Interprocessor communications are via TCP/IP using Ethernet cables and tactical-radio-frequency modems.

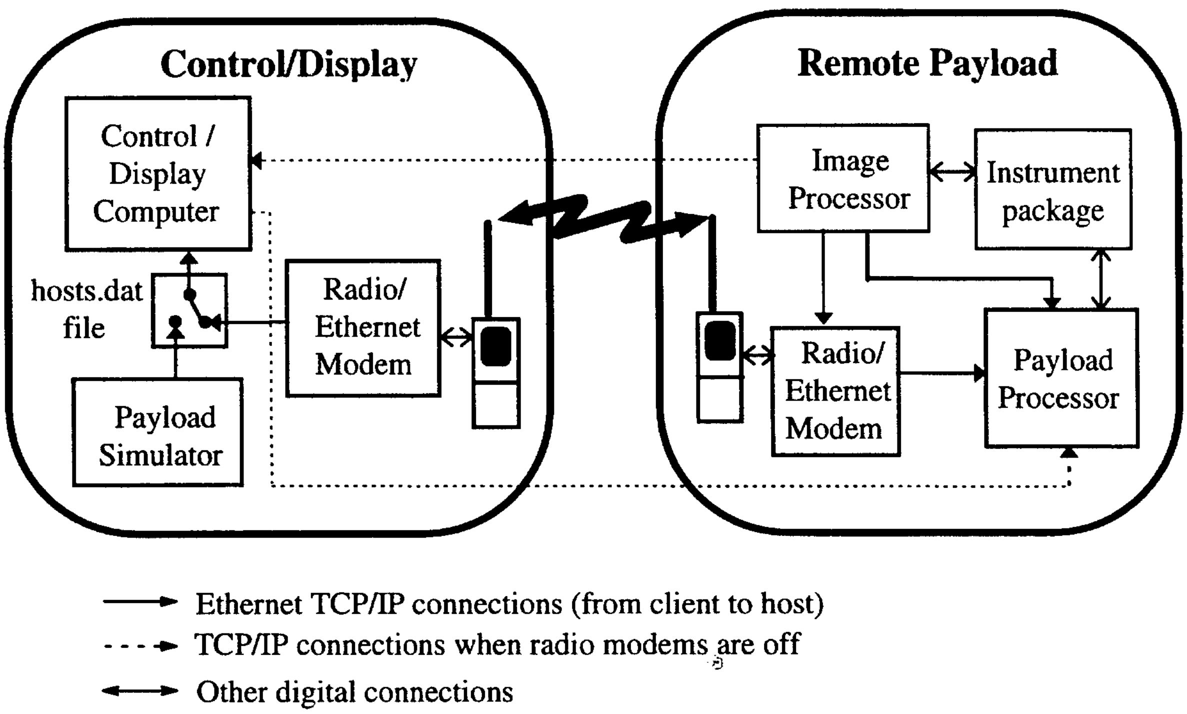

Figure G-1. AMGSSS MPP system.

Functional requirements for the AMGSSS Mission Payload Prototype Control Display Station include:

- Portability, for ease of concept demonstration.
- User-friendly control and display operations.
- Easily scalable architecture
- Ethernet TCP/IP connectivity
- Displays 256 colors, with capability for video streaming

To meet these objectives, we selected an IBM ThinkPad 755 CD laptop computer (with a 100-MHz 80486 processor) for control display functions. It has 256-color active matrix display, a docking station for functional scalability, provides Ethernet connectivity via a PC-Card plug-in

module, and has built-in video display functions (this last feature may be used for video streaming in the future, but currently is not utilized). A PC-104 single-board computer provided the Ethernet-to-radio modem functions (reference G-1), and is packaged together with a hand-held field radio in a RF-shielded package, as shown in figure G-2.

Figure G-2. MPP control display station.

The system employs a message-passing distributed processing architecture. Messages and commands are passed between the subsystems via the Ethernet cables and via the radio link between the control and payload ends. Each computer has an Internet (IP) address and uses a hosts data file ("hosts.dat") to find the Internet addresses of the other modules. The network protocol is set up to automatically switch to an all-direct Ethernet configuration, by-passing the radios, upon detecting the absence of the radio modems. This was intended as an early developmental configuration, but proved very useful throughout the developmental cycle and later as a valuable demonstration tool.

TCP/IP and message-passing distributed processing also allows subsystems to be added with ease. A new subsystem component would only require an additional item in the hosts data table, and perhaps additional messages defined for the specific new subsystem. No hardware changes to the existing subsystems are required. Subsystem substitutions are also easily accomplished by changing the TCP/IP addresses in the hosts data table. We added a payload simulator late in the development cycle to help debug the control display software before the payload was completed, with no changes to existing hardware or software (reference G-2).

CONTROL DISPLAY SOFTWARE ENVIRONMENT

Both the control display program and the payload simulator program operate under the Microsoft Windows Graphic User Interface (developed under Windows 3.1, although they also work under Windows 95). Both were developed using the Microsoft Visual C++ compiler. The Microsoft Foundation Class library was used to provide the basis for object-oriented programming. We used Trumpet Winsock 2.0 to provide the TCP/IP interface under Windows 3.1 (Windows 95 provides its own TCP/IP driver).

CONTROL DISPLAY PROGRAM

Figure G-3 shows the top-level functional breakdown of the control display program. At the heart of the program is the database ("document" in Visual C++ lingo), containing information about images collected, status of all sensors and subsystems, maps, and alerts received. The database supports three "views": the status view with status of all three AMGSSS remote payloads (although only one payload has been developed for this demonstration); the geographic view with sensor information overlaid on top of a map of the operational area; and the situation view, which gives the operator a "big picture" of how all the images collected, programmed motion and acoustic scanning programs, and alerts that have come in are interrelated. In addition, there are two independent windows (displaying the panorama scene and any high-resolution snap shot) that can be displayed on top of any view. Communications between the database and the views are through Windows message-handling mechanisms.

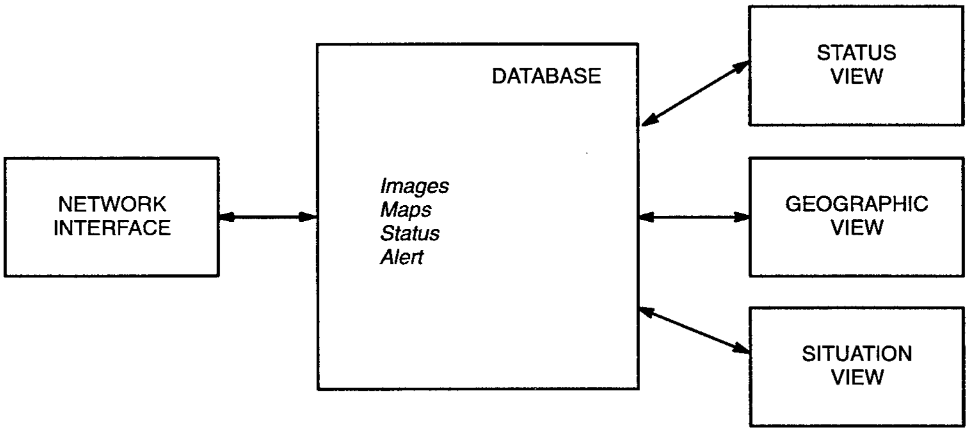

Figure G-3. Control display program functional breakdown.

The Status View

The status view is a text screen providing status information on all subsystems, sensors, and radio links (see figure G-4). Status displays for three MPPs are available, although only one is active due to the availability of only one MPP. Status messages on the radio link are provided by the radio computers (to the control display computer on the control side, and to the payload processor on the remote side) every 10 seconds. The payload processor assembles all sensor and remote subsystem status messages and forwards them over the radio link to the control display every 30 seconds. In addition to the information presented by the status view, a green status light in the upper left-hand corner of all views acts as the system's heartbeat. It blinks every time a message comes over the radio link and becomes gray if the link is down. This enables the operator to monitor the overall system status even when the display is showing the geographic or situation view.

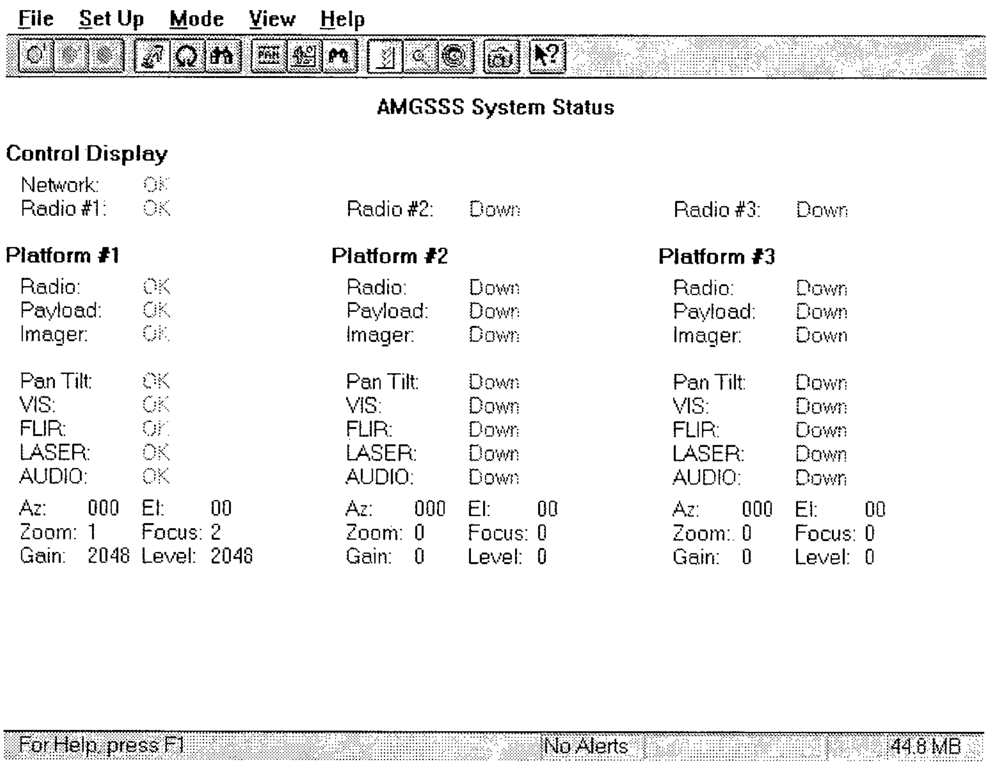

Figure G-4. Control display status view.

The Geographic View

The geographic view revolves around a map of the operational area. Initially, we used a vector map to allow display at multiple scales. However, we found that the vector maps we could find (in this case, the Central Intelligence Agency's World Database maps) were of insufficient detail. So we switched to multi-resolution scanned raster topological maps. Figure G-5 is a screen capture of the geographic view showing the topological map, overlaid laser ranging results (the lines ending in stars—clicking on the stars brings up a box with range, time, and azimuth and elevation information), motion alert (the triangle), and visual angle of displayed images (the shaded wedge corresponds to the center image in the panorama). The panorama images are not part of the geographic view itself and can be pulled up on any of the three views. All screens and operational images showed here have been obtained during a system operational test at Mission Trails Regional Park in San Diego, California, in late October 1995.

The Situation View

The main function of the situation view is to present a clear picture of the relationships between all collected images, planned panorama and motion scans, laser ranges and alerts currently in the system database. The view is laid out as three concentric rings representing +45 degrees, 0, and -45 degrees in elevation. Superimposed on these rings are wedge sections correlating to images collected or scans to be executed. Figure G-6 shows two rings of panorama images (overlapping in elevation), the lighter box on the inner ring corresponds to the center pane in the panorama image strip above. The operator can select the amount of information to be displayed on the view by clicking on the items listed at the lower left corner of the screen.

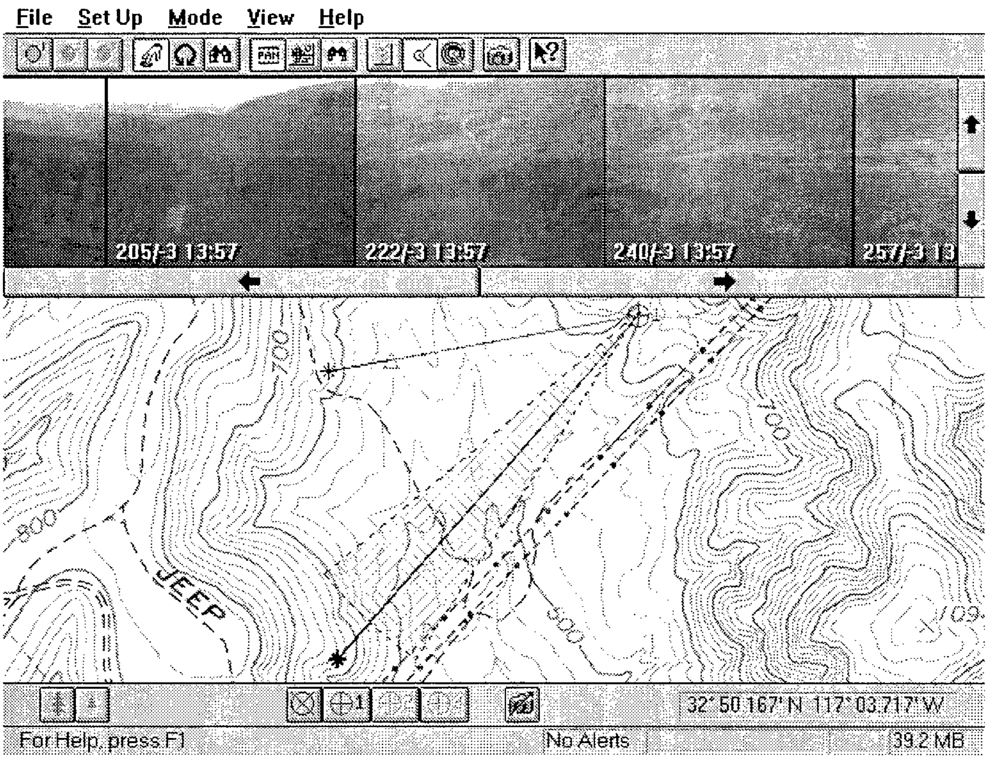

Figure G-5. Control display screen showing the geographic view and panorama images.

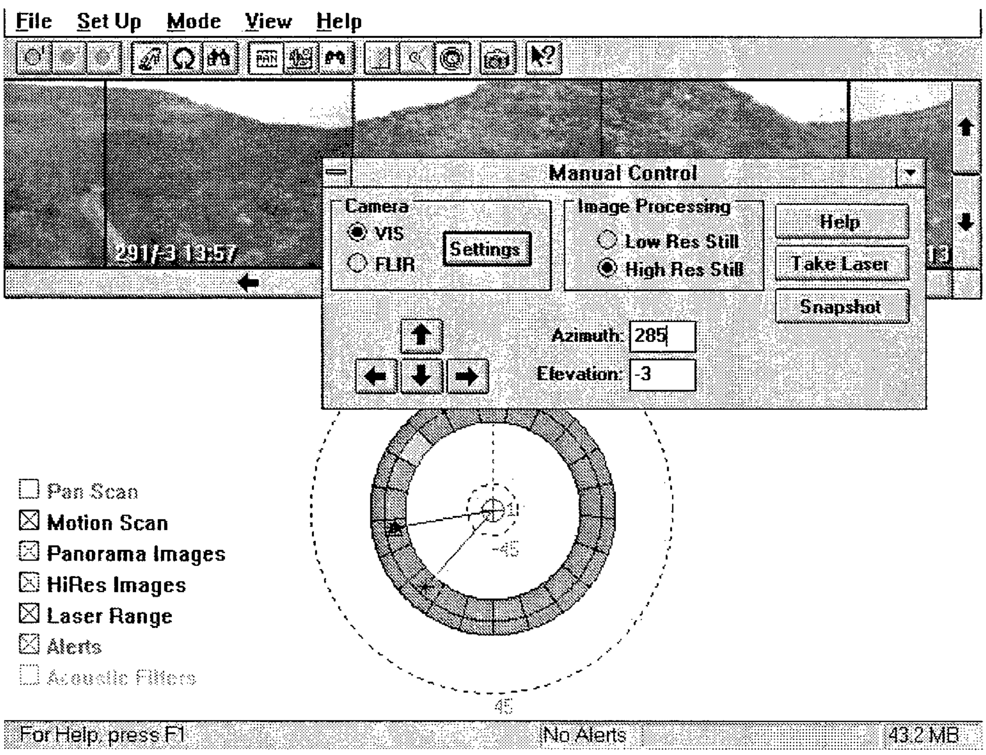

Figure G-6. Control display screen showing the situation view, panorama images, and a manual control dialog box.

Programmed Execution and Responses

Besides the capability for manual control of the sensor package (figure G-6 shows a typical manual control dialog box), the AMGSSS control display program also offers several program modes to simplify the operator's workload. The operator can program the system to perform panoramic sweeps to get a feel for the general landscape (figure G-6 shows two panorama rings, at –3 and +5 degrees in elevation). Likewise, the system can be programmed to look for motion at certain locations and at some sensitivity, using the visible or infrared camera. Acoustic detections can also be filtered. Only certain categories (ground vehicle, jet, propeller planes, etc.) or all can be passed to the operator.

Programmable responses to alerts include automatic capture and transmission of a low- or high-resolution image, automatic range determination via the laser rangefinder, or a return to manual control. Figure G-7 shows a motion alert and associated high-resolution image showing a moving HMMWV on a dirt road.

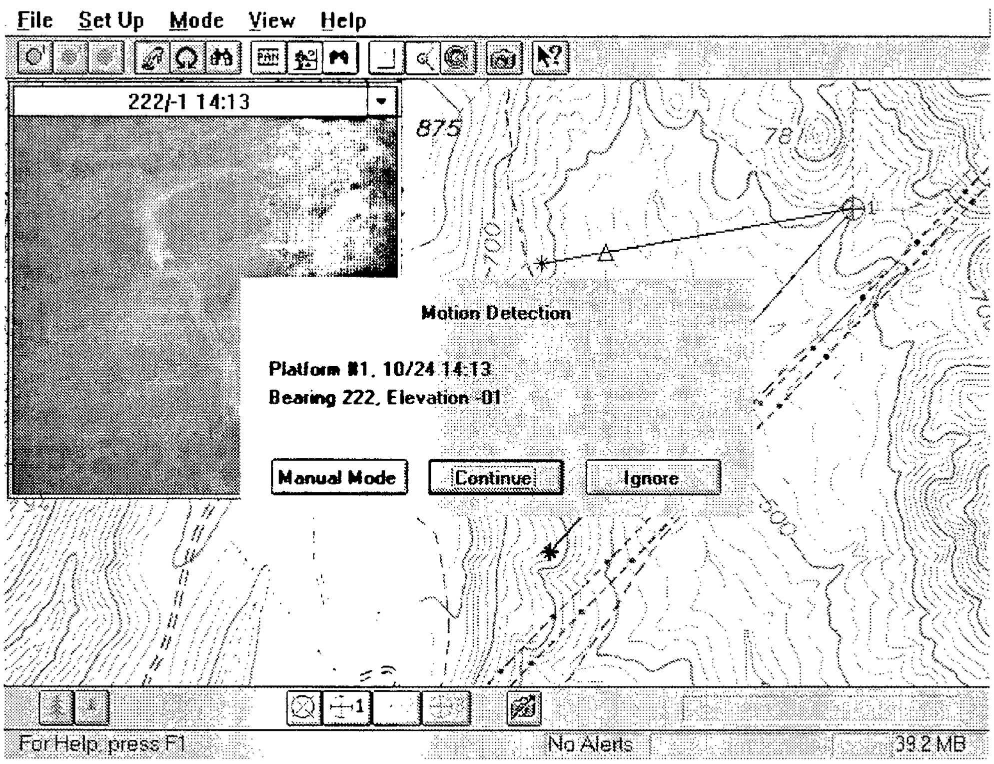

Figure G-7. Control display screen showing motion detected.

CONCLUSIONS AND RECOMMENDATIONS

The control display station has been developed to meet the immediate needs of the AMGSSS Mission Payload Prototype. In order to expand the system to the original AMGSSS system objectives (references G-3 through G-6), various changes will be needed. Among them are:

- Conversion to a 32-bit operating system, such as Windows-NT. The power of a 32-bit operating system will be needed to address the following four issues.
  - — Incorporating 3-D maps, such as DMA-supplied DTED (elevation data) and ADRG (raster) maps. A combination of maps such as the two mentioned will be necessary to

generate a 3-D map of the environment to enhance operator awareness and allow mission planning on the control display station.

- Adding mission planning capabilities. This includes programming and supervision of the flight and landing of the air-mobile platforms.
- Expanding support to three air-mobile platforms/sensor suites.
- Addition of the video-streaming capability.

• Enhancing the user interface based on feedback from operators during field tests.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1996	Final: FY 95 – FY 96

4. TITLE AND SUBTITLE

AIR-MOBILE GROUND SECURITY AND SURVEILLANCE SYSTEM (AMGSSS) PROJECT SUMMARY REPORT

5. FUNDING NUMBERS

DSWA(DNA): MIPR 96–2102
WU: 82307
PSEMO: MIPR 66041
PE: 0604322D
AN: DN301040

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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RDT&E Division
San Diego, California 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

NRaD TD 2914

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited.	

13. ABSTRACT *(Maximum 200 words)*

This document summarizes the Air-Mobile Ground Security and Surveillance System (AMGSSS) project. The AMGSSS system is designed to rapidly position remotely operated ground sensors at locations of operational interest and to provide information obtained by those sensors back to the operator.

14. SUBJECT TERMS

Mission Area: Robotics
ground surveillance
mobility
AMGSSS
physical security

15. NUMBER OF PAGES

85

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE *(include Area Code)*	21c. OFFICE SYMBOL
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NSN 7540-01-280-5500

Standard form 298 (BACK)

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